CALIFORNIA
ENERGY
COMMISSION

NIGHTBREEZE PRODUCT AND TEST INFORMATION

NightBreeze Owner's Manual

NightBreeze Installation Instructions

Advanced Control Functional Specification

Advanced Control Functional Enhancements Report

Integrated Heating, Ventilation and Cooling Unit Test Report

Damper Test Report

TECHNICAL REPORT

February 2004
P500-04-009-A1

DAVIS ENERGY GROUP
INCORPORATED

STATE OF CALIFORNIA ENERGY COMMISSION

Arnold Schwarzenegger, *Governor*

Prepared By:
Davis Energy Group
Dave Springer
123 C Street
Davis, California 95616
Contract No. 500-98-024

Prepared For:

California Energy Commission

Phil Spartz
Project Manager

Nancy Jenkins
PIER Buildings Program Manager

Terry Surles
PIER Program Director

Robert L. Therkelsen
Executive Director

Preface

The Public Interest Energy Research (PIER) Program supports public interest energy research and development that will help improve the quality of life in California by bringing environmentally safe, affordable, and reliable energy services and products to the marketplace.

The PIER Program, managed by the California Energy Commission (Commission), annually awards up to $62 million to conduct the most promising public interest energy research by partnering with Research, Development, and Demonstration (RD&D) organizations, including individuals, businesses, utilities, and public or private research institutions.

PIER funding efforts are focused on the following six RD&D program areas:

- Buildings End-Use Energy Efficiency
- Industrial/Agricultural/Water End-Use Energy Efficiency
- Renewable Energy
- Environmentally-Preferred Advanced Generation
- Energy-Related Environmental Research
- Energy Systems Integration

What follows is an attachment to the final report for the Alternatives to Compressor Cooling Phase V project, Contract Number 500-98-024, conducted by Davis Energy Group. This project contributes to the PIER Building End-Use Energy Efficiency program.

This attachment, "NightBreeze Product and Test Information" (Attachment A-1), provides supplemental information to the project's final report and includes the following six reports:

- *NightBreeze Owner's Manual*
- *NightBreeze Installation Instructions*
- *Advanced Control Functional Specification*
- *Advanced Control Functional Enhancements Report*
- *Integrated Heating, Ventilation and Cooling Unit Test Report*
- *Damper Test Report*

For more information on the PIER Program, please visit the Commission's Web site at: http://www.energy.ca.gov/research/index.html or contact the Commission's Publications Unit at 916-654-5200.

Abstract

This "NightBreeze Product and Test Information" attachment is a set of six documents produced by the Alternatives to Compressor Cooling Phase V project, funded by the California Energy Commission's Public Interest Energy Research (PIER) Program.

The Alternatives to Compressor Cooling (ACC) Phase V Project has the goal of reducing residential peak load in California by using nighttime ventilation to cool houses that are designed for optimal summer performance and that potentially eliminate the need for air conditioning in transition climates.

This attachment, "NightBreeze Product and Test Information" (Attachment A-1), provides supplemental information to the project's final report and includes the following six reports:

NightBreeze Owner's Manual
The User's Manual for the integrated heating, ventilation, and cooling unit developed by Davis Energy Group for the ACC Phase V project.

NightBreeze Installation Instructions
The Installation Instructions for the combined heating, ventilation, and cooling unit developed by Davis Energy Group for the ACC Phase V project.

Advanced Control Functional Specification
This specification defines physical and operational criteria for an advanced control that operates an integrated system that provides night ventilation cooling system, heating , air conditioning, and fresh air ventilation. This document includes both firmware and hardware specifications for the production model of the control developed by Davis Energy Group and RCS, respectively.

Advanced Control Functional Enhancements Report
This report outlines results of computer simulations performed to identify optimal parameters for the NightBreeze system control unit.

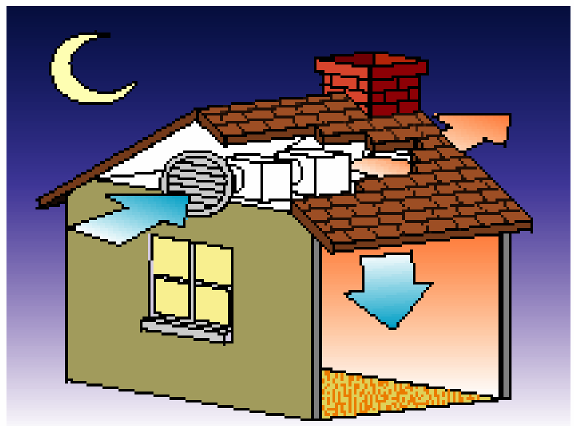
Integrated Heating, Ventilation and Cooling Unit Test Report
This report describes results of testing on the integrated heating, ventilation, and cooling unit developed by Davis Energy Group in the ACC Phase V project. Tests were completed by the Pacific Gas & Electric Company (PG&E) Technical and Environmental Services Center (TES), and evaluation and reporting of test data was completed by Davis Energy Group (DEG).

Damper Test Report
This report describes results of testing on the damper for the integrated heating, ventilation, and cooling unit developed by Davis Energy Group in the ACC Phase V project. Tests were completed by the Pacific Gas & Electric Company (PG&E) Technical and Environmental Services Center (TES), and evaluation and reporting of test data was completed by Davis Energy Group (DEG).

NightBreeze

Integrated Heating, Ventilation, and Cooling System

Owner's Manual



Contents

System Description

What is NightBreeze?

The NightBreeze system was developed by researchers to eliminate the need for air conditioning in mild climates and reduce the size of air conditioners in hotter climates, and to provide improved indoor air quality and comfort. By following these instructions carefully you can insure that you will experience the comfort and energy savings the system was designed to provide.

How is the NightBreeze System Different?

The NightBreeze system heats and cools your house just like any other furnace-air conditioning system, by delivering warm or cool air through ducts to each room. Features that distinguish the Night-Breeze from other systems include:

• An automatic damper that allows the house to be ventilated and cooled using filtered outside air, without the necessity to open windows

• A control system that anticipates hot weather and automatically ventilates your house with cool night air to provide optimal comfort while minimizing air conditioner energy use

• A quiet, efficient, variable speed blower that provides just the amount of airflow needed to meet heating and cooling needs

• A furnace that obtains its heat from your water heater instead of from direct gas combustion, thereby improving household safety

• A thermostat that is easy to use and provides built-in "help"

How Does Ventilation Cooling Work?

On summer evenings in many areas of the country people open windows to ventilate their homes with outdoor air, both to obtain natural cooling and to remove stale air. The cool air absorbs heat from warm interior surfaces and furnishings. In the morning windows are closed and the cool surfaces absorb heat during the day, keeping the house cool and comfortable. Houses with more massive walls and floors store this "coolth" more effectively. The lower the temperature the house reaches at night, the more comfortable the house stays during the day.

Managing windows in this manner reduces the need for air conditioning and saves energy, but personal schedules and security concerns may interfere with using windows for ventilation. Also, there may not be sufficient outdoor breezes to adequately flush the house with cool air.

NightBreeze provides ventilation cooling automatically, eliminating the necessity of operating windows (though it is still good practice.) NightBreeze uses the heating/air conditioning system fan to bring in filtered outside air and flush out warm, stale indoor air.

The system also allows you to select the lowest temperature you want the house to reach overnight. As the weather becomes more mild, the system automatically decreases the amount of ventilation to prevent the house from being over-cooled.

What If I Still Need Air Conditioning?

In addition to allowing you to set your lowest acceptable indoor temperature, you can set the highest temperature that you want the house to reach. The air conditioner (if you have one) will operate if the house rises above this high temperature setting. The special thermostat allows you to see whether the air conditioner is likely to operate, given your high and low temperature settings and current weather conditions.

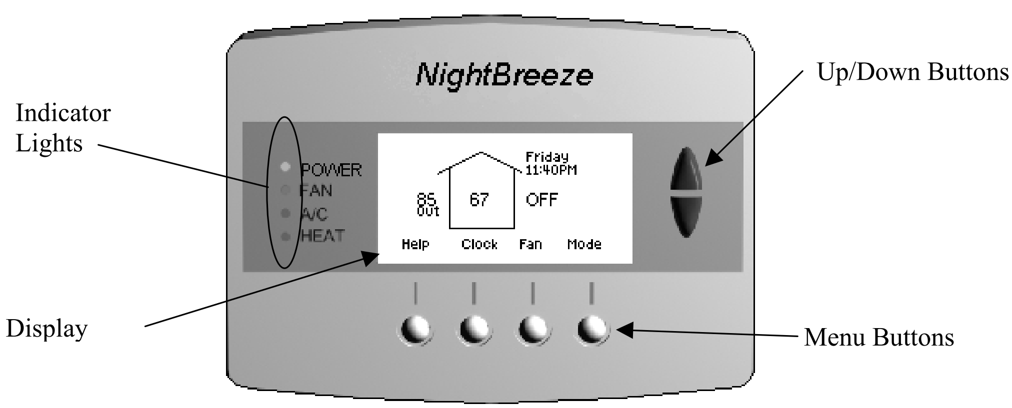
How Does the Heating System Work?

Unlike gas furnaces that obtain heat directly from combusted gas, NightBreeze circulates water from your water heater to a coil that is similar to the radiator in your car. A blower circulates air through the warm coil and into your house. The speed that the blower operates varies with the amount of heating that is needed, and thus it is very quiet. Most of the time you may not even be aware it is running.

Using The Thermostat

Understanding the Thermostat Buttons and Display

There are four buttons along the bottom of the thermostat and two on the right of the display that are used to make temperature and other settings. The functions of these buttons are described by labels on the display. Referring to the picture below, the button on the bottom right sets the operating "mode" (heating, cooling, etc.). These labels may change, depending on what settings are being made. The two up/down buttons on the right side of the display are primarily used to adjust temperature settings, though they are also used for setting the clock and heating schedule times. The thermostat has four colored lights to the left of the display that indicate what the system is doing. The top (green) light indicates the system is turned on in one of the three modes. The Fan, A/C, and Heat lights tell whether the fan, air conditioner, or furnace are operating, respectively.



Thermostat – Shown in *Off* Mode

The number located inside the house icon on the display screen is the indoor temperature. The temperature to the left of the house is the outdoor temperature. A window in the house icon opens when it is cooler outdoors than indoors, indicating that windows can be opened to ventilate the house in summer. Day of the week and the current time are also shown in the upper right of the display.

Arrows appear on the screen to indicate if the system fan is running. Different arrows are used to indicate whether the fan is recirculating indoor air, or ventilating with outdoor air (see *Operating the Fan Manually* for examples).

"Help"

The left button provides "help" instructions that describe the purpose of each of the other buttons. Help information is accessed by first pressing the "help" button, then the button in question.

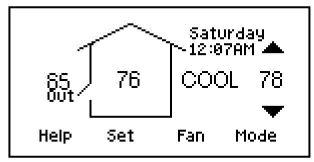
Operating Modes

The NightBreeze thermostat has four operating "modes": *Off*, *Cool*, *Heat*, and *Vacation*. In *Cool* mode the system will only provide cooling, and in *Heat* mode the system will only provide heating. In *Vacation* mode the system will provide both heating and cooling, if needed. Temperature settings for ongoing daily operation can be changed in *Heating*, C*ooling*, and *Vacation* modes. In either heating or cooling mode you can also override permanent, or "long-term" settings to make temporarily changes to these temperature settings.

***OFF* mode** is used to turn the system off (no heating, cooling, or ventilation), and to access clock settings.

***COOL* mode** is used to maintain summer comfort, either by operating nighttime ventilation cooling only, or using ventilation cooling and air conditioning. To see how to enter *Cool* mode temperature settings, follow the directions below:

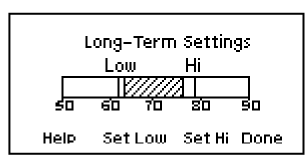
1) Press the button labeled *Mode* until the following image appears in the thermostat display:



Cooling Mode

In the above example, the indoor temperature is 76°, the outdoor temperature is 65°, and the number on the right shows that the air conditioner will turn on at 78°. An open window in the house icon indicates it is cooler outside than inside and that windows can be opened for ventilation cooling.

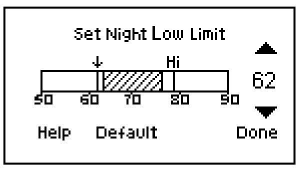
2) Press the button marked *Set* to adjust "long-term" temperature settings. The display will appear similar to the figure below.



Cooling Mode
"Long Term" Settings

The "comfort bar" shows two temperature settings. The "Low" setting is the lowest temperature that the house will be cooled to by ventilation, and the "Hi" setting is your maximum desired temperature, and also the temperature at which the air conditioner will start (if you have one). The shaded portion of the bar indicates the predicted range of indoor temperatures for the next day.

3) Press *Set Low*. This allows you to adjust the lowest temperature that you want the house to be cooled to using ventilation. The flashing arrow that appears above the temperature bar in the example below indicates that you can now set the "Low" temperature.

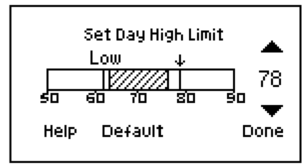


Cooling Mode
Low Limit Setting

4) Use the two triangular (up/down) buttons to the right of the display to adjust the "low" temperature setting. Note that as this setting is raised (by pressing the "up" button), the predicted temperature range (shaded bar) moves to the right. If the shaded bar crosses the "Hi" setting, the message "AC will run" is displayed, to indicate that your current settings are likely to result in air conditioner operation the following day. As you lower the setting the comfort bar will move to the left and will stop at some point. This is because you cannot cool your house lower than the outdoor air temperature.

5) Press *Done* to accept the temperature settings you entered.

6) Press *Set High*. This allows you to set the highest temperature you would like the house to attain, which is also the temperature at which the air conditioner will turn on. Adjust the temperature setting using the up/down arrows. Again, if you lower this "Hi" temperature setting so that it falls within the shaded bar, the message *A/C will run* will be displayed.

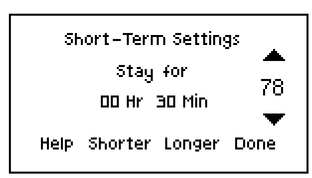


Cooling Mode
High Limit Setting

7) Press *Done* twice. This returns you to the *Cool* display, and allows the system to operate using the *Long-Term* settings you have made.

The shaded comfort bar will change each day (at midnight) so that it is always predicting the next day's indoor minimum and maximum temperatures. During cooler weather the comfort bar will shrink, since less nighttime ventilation cooling will be needed to avoid high afternoon indoor temperatures.

Next, try adjusting *Short-Term* cooling settings. This feature is for temporarily raising or lowering the indoor temperature if your *Long-Term* settings are not providing the level of comfort you want at the current time. Press either the up or down button on the right side of the screen - the following screen will appear:



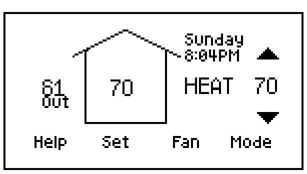
Short-term Settings

Press the up/down buttons again to raise and lower the temperature to the desired setting. The new temperature setting is displayed (78° in the example). Press *Shorter* or *Longer* to decrease or increase the length of time that you want the house to stay at the new temperature (30 minutes in the example). Press *Done* to accept these settings. The displayed temperature setting will blink to indicate that short-term settings are in effect. You may cancel short-term settings by pressing the *Cancel* button once.

HEAT Mode is used to maintain winter comfort. Temperature settings can be entered for each of four different time periods per day. Also, different time and temperature schedules can be set for weekdays and weekends.

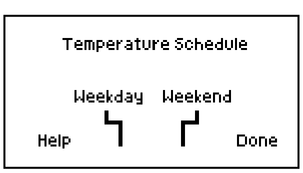
In winter the outside air damper operates only to maintain indoor air quality. The volume of fresh air provided can be adjusted based on the size of the house and/or number of occupants (see *Advanced Settings*).

To select heating mode, press the mode button until *Heat* is displayed. The following screen will appear:



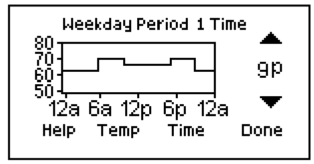
Heat Mode

Press *Set* to change temperatures and time schedules and you will see:



Heating Schedule Options

Press *Weekday* to select the temperature schedule to be used for Monday through Friday. The graph that appears (Weekday Heating Schedule) is a profile of the temperatures at which your house will be maintained, and the times that the temperature will be changed during the day and night.



Weekday Heating Schedule

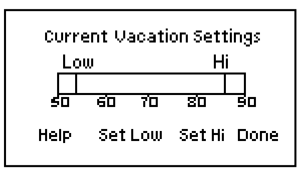
The temperature for the first time period is indicated by the horizontal line at the far left and right of the graph. In the example above this period is from 10 PM to 6 AM.

To modify the temperature for the first time period press *Temp*, then press the up/down buttons to adjust the temperature, which is indicated by the graph and also shown to the right of the screen. If you want to increase or decrease the length of time that this temperature is maintained, press *Time*, and adjust the time, also using the up/down buttons. The time will also be displayed both by the graph and by digits to the right of the screen (as shown in the example). Each time you press the *Temp* or *Time* button you will advance to the next time/temperature period. The blinking horizontal or vertical line on the graph shows you which time or temperature you are adjusting. When you have finished setting the temperatures and times for all four periods press *Done* to accept these settings, and *Weekend* to set your heating schedule for weekend days.

You may use the up/down keys, the same as in cooling mode, to temporarily override your usual (long-term) temperature settings. And, as in cooling mode, you may select the temperature and the length of time you want this temperature maintained.

VACATION Mode is used to set upper and lower temperature limits while you are away for extended periods of time. In this mode the thermostat will use the ventilation system, air conditioner, and heater as needed to maintain indoor temperatures within the selected limits. Wider settings (for example 55º low and 85º high) may completely eliminate furnace and air conditioner use, and will result in lower energy costs.

To use vacation mode, press the mode button until *Vacation* is displayed, then press *Set* and the following screen will appear:



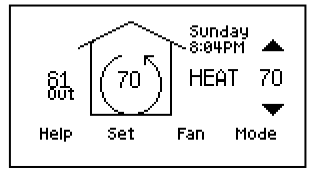
Vacation Settings

The temperature bar is similar to that used for cooling settings, except that predicted indoor temperatures are not shown.

Press *Set Hi* to set the upper temperature limit and *Set Low* to set the lower temperature limit. Use the up/down keys to adjust the temperature for each setting. To accept your settings and return to the main display, press *Done*.

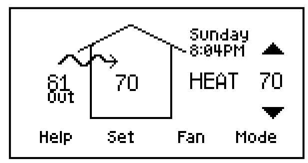
Operating the Fan Manually

Normally the fan operates automatically, and only while the system is ventilating, heating, or cooling. However, you may manually turn on the fan from any operating mode except *Vacation* by pressing the *Fan* button. If you press the button once, a circular arrow inside the house icon will blink, indicating that the fan is recirculating indoor air, as shown in the following screen:



Fan On – Recirculating Indoor Air

If you press the fan button a second time, a squiggly arrow will appear, indicating you are ventilating the house with outdoor air, as shown in the screen below.



Fan On – Ventilating with Outside Air

Pressing the fan button a third time will revert to automatic fan operation, or after one hour the fan will return to automatic operation by itself.

Note that these arrow symbols appear any time the fan is operating, but the arrows only blink if the fan has been turned on manually.

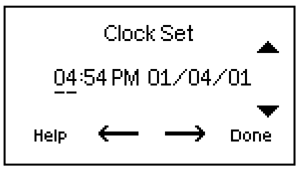
Manual fan operation may be useful if you want to remove indoor odors, or just mix indoor air. The fan consumes energy, so routine manual operation of the fan is not recommended.

Winter Ventilation

To keep indoor air fresh, the fan and damper will operate while the thermostat is set to heating mode to ventilate your house with a small volume of outside air each hour. This volume of air was set by your installer using the Advanced Settings feature of the thermostat. Advanced settings are described in a later section of this manual.

Setting the Clock

The NightBreeze thermostat has a permanent battery that retains clock time through power outages up to several hours. If you want to change the time, for example to adjust for daylight savings time, press the mode button until *Off Mode* is displayed. Then press *Clock*. The following screen will appear:



Setting the Clock

Use the left and right arrow (two middle) buttons to position the cursor (underline) under the hours, minutes, day, month, or year. Use the up/down buttons to the right of the display to modify the time or date. Press *Done* when you have finished, and the press the *Mode* button to return to your preferred operating mode.

Operating Recommendations

Summer Operation

By allowing your house to cool off as much as possible at night you will reduce the amount of air conditioning you will need. The following tips will help you to save energy and stay comfortable:

- Set the low limit temperature to 65° or lower
- Set the high limit temperature to 80°
- Open windows when convenient to assist fan ventilation (but only when the window is open on the thermostat house icon)
- Minimize the use of short-term temperature settings
- Use window coverings to block out the sun during the day

Winter Operation

The following tips will also help you stay warm and comfortable during the winter months:

- Use lower temperature settings for periods when the house is not occupied
- Keep your windows closed and let the system provide fresh air ventilation
- Minimize use of short-term temperature settings
- Use window coverings to keep heat in at night, and open them to allow in heat from the sun during the day

Spring and Fall

Turn off the system and let the house coast, using windows for ventilation when needed.

Maintaining Your System

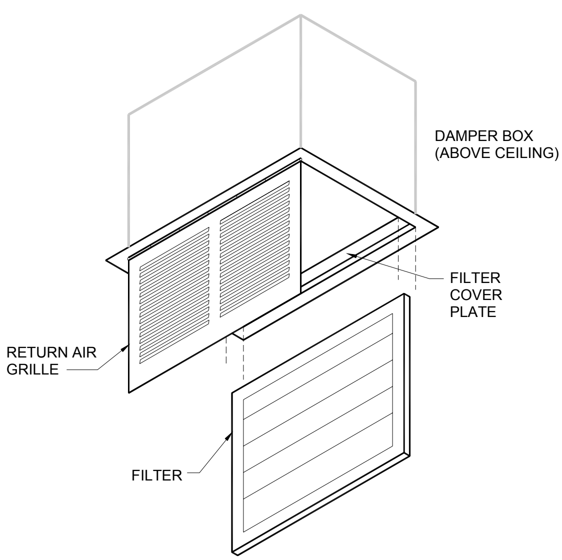
Changing the Filter

The NightBreeze filter cleans outdoor air that is used to ventilate the house, as well as indoor air that is recirculated. As a result it may require more frequent changing than you are accustomed to. A dirty filter will not appreciably reduce the rate of air delivery to your house, but it will cause the fan to work harder and will increase your energy bill.

For best results, change your filter every 3 months. If you live in an area with a large amount airborne dust or pollens you should inspect the filter monthly and replace it as needed.

The recommended filter for NightBreeze is the 3M Filtrete 1000 or 1250. Filter dimensions are 20" x 30" x 1".

To access the filter, locate your ceiling return air grille. Rotate the two fasteners located on the rim of the grille opposite the hinge (turn counterclockwise), and allow the grille to swing down. Then rotate the two retaining clips holding the filter cover plate in place and open the cover. Carefully withdraw the filter, install the recommended replacement, and close the filter cover and grille.



Other Maintenance

Besides changing the filter, no other routine maintenance is required. However, you should:

- Keep the outside air intake clear of leaves and other debris
- Take precautions to avoid damage to the outdoor temperature sensor (located near the outside air intake)
- Keep your water heater in good operating condition, since it is the source of heat for the NightBreeze

Advanced Control Settings

Certain control settings were made by your installer to configure the NightBreeze system to the particular conditions under which it was installed.

You may find it useful to access some of these settings to:

- Re-calibrate indoor and outdoor temperature sensors
- Modify the maximum fan speed for ventilation cooling or manual vent.
- Change the fresh air ventilation rate
- Deactivate the air conditioner

To access the *Advanced Settings* menu select *Off* mode, then hold down the up and down buttons at the same time until the menu appears. Refer to the Installation Manual before making any changes to these settings.

NIGHTBREEZE®

INSTALLATION INSTRUCTIONS

Model NB10-2-120A

Variable Speed Ventilating Hot Water Air Handler
Horizontal or Upflow

Heating to 60,000 Btuh • Cooling to 5 tons
Ventilation Cooling to 2200 cfm

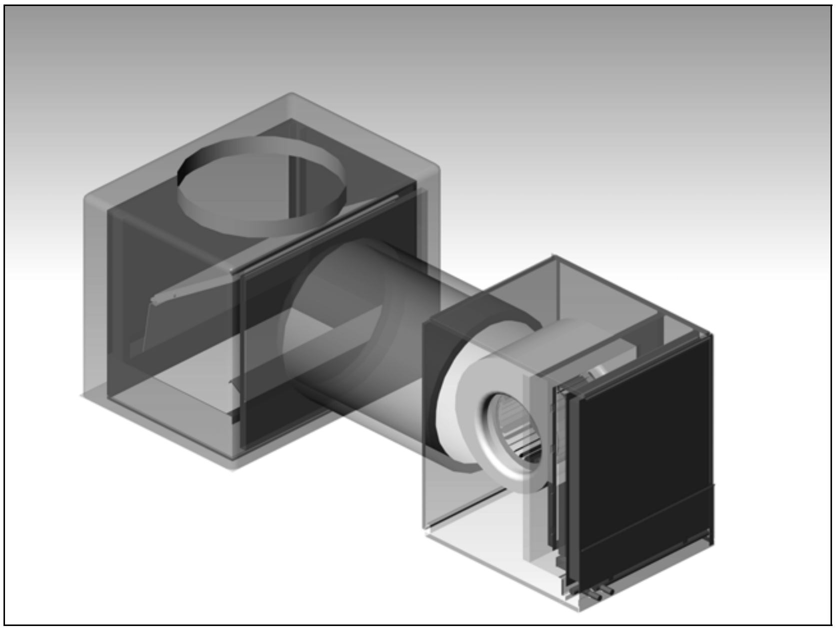


TABLE OF CONTENTS

IMPORTANT NOTES TO INSTALLER

- Review these instructions thoroughly prior to beginning installation.
- Installation of the NightBreeze system must conform to local building, mechanical, and plumbing codes.
- Before attempting to perform any service or maintenance, turn the electrical power to unit off at the disconnect switch.
- Provide these instructions to the owner for future reference.

PRODUCT DESCRIPTION

Air Handler

NightBreeze is a residential comfort system that integrates heating, cooling, ventilation cooling, and fresh air ventilation to provide exceptional indoor comfort and air quality. The horizontal/upflow air handler incorporates a variable speed blower powered by a G.E. ICM2 motor, a hot water heating coil, a built-in circulating pump, and controls. The blower motor is programmed to deliver a constant airflow rate over a wide range of external static pressures, and provides full variable speed operation (200 - 2100 CFM) in heating mode. The heating coil is connects to a water heater or boiler and a circulating pump delivers hot water to the coil. DX cooling coils from 1½ to 5 tons may be added.

Damper

An automatic damper couples to the air handler and allows the system to ventilate using 100% outside air. The damper, which installs above the return air opening in the ceiling also vents indoor air to the attic. A duct connects the damper to a louver or roof vent to provide the fresh air supply.

Controls

Controls provided with the NightBreeze system include a microprocessor-based thermostat, an outdoor temperature sensor, and an electronic control module (installed in the air handler). The thermostat allows separate temperature settings for cooling, heating, and vacation operating modes. The thermostat also provides for short-term (override) settings and manual fan operation. All settings are preserved during power losses by a capacitor. Consult the Owner's Manual for additional information on control operation.

Instead of using speed taps at the air handler to set heating and cooling airflow rates, all settings are made at the thermostat. Pressing and holding the two up/down adjustment buttons at the same time will display the Advanced Settings menu. These settings can then be selected using the up/down buttons. Refer to **Control Setup** for information on all settings.

Description of Operation

NightBreeze controls allow four operating modes: *Off, Cooling, Heating,* and *Vacation.* These and other control functions are described below.

Cooling: During the cooling season the air handler ventilates the house with 100% outside air when it is 5° cooler[1] outdoors than indoors (usually at night). The damper draws in outside air and relieves indoor air through the return air grille.

The ventilation cooling airflow rate varies daily with cooling load and is updated each day at midnight. The control records indoor and outdoor temperatures from prior days, and uses this history to predict temperatures for the next day. The predicted indoor temperature range is indicated by the shaded portion of the thermostat's "comfort bar" (press *Set* to view). If hotter weather is predicted, the fan operates at higher speeds. The spacing between the shaded bar and the "Hi" setting is one indicator of how fast the fan will run. If the shaded bar touches or crosses the "Hi" setting, the fan will likely run at the speed selected under "Vent Fan CFM" in Advanced Settings.

A low limit temperature setting prevents the house from being overcooled during mild weather. If ventilation cooling is not sufficient to prevent the indoor temperature from exceeding the high limit temperature setting, the system operates the split-system air conditioner, if one is provided. If it is cooler outdoors than indoors while the air conditioner is operating, the damper operates as an economizer, selecting outside air instead of return air. If an air conditioner is installed, the air conditioning airflow rate must be properly set using the Advanced Settings menu and Cooling Mode must be set to "Standard".

Heating: The circulating pump circulates hot water from the boiler or water heater to the built-in coil. The blower delivers warm air at a rate proportional to the heating demand. Maximum airflow is delivered when the indoor temperature is 5° below the thermostat setting, and airflow decreases as the air temperature approaches the thermostat setting.

Vacation: If Vacation mode is selected the system maintains indoor temperatures between low and high temperature settings, automatically switching between heating and cooling modes as needed. Cooling is provided by outside air ventilation when it is cooler outdoors than indoors, and by the split-system air conditioner when it is not.

Heating Mode Fresh Air Ventilation: While the system is in heating mode, the outside air damper and fan operate once per hour to provide fresh air ventilation. If the heating system operates at any time during a given hour, the damper will open long enough to deliver the average hourly ventilation rate, which is set at the thermostat using the Advanced Settings menu. The length of time the damper is open varies with blower speed to maintain the proper level of ventilation. For example, if heating demand is high and the fan is running at a high speed, the damper will not stay open as long. If the supply air temperature drops below about 100°, the damper will close to prevent discomfort from cold drafts.

If the fresh air requirement is not fully satisfied while the system is providing heating, or if no heating is needed during the hour, the system waits until the end of the hour to activate the fan and damper. It will then operate the fan to deliver outside air at a rate of about 200 CFM for the required duration. At outside temperatures below 45° the control will automatically activate the pump to temper outside air. At outside temperatures below 35° fresh air ventilation is discontinued to prevent the possibility of freezing the heating coil in the event of a pump failure. Fresh air ventilation can be turned off by setting *Ventilation Rate* to 0 in Advanced Settings.

[1] The 5° temperature differential can be modified in the Advanced Settings menu.

PERFORMANCE TABLES

Table 1 BLOWER DATA						
	CFM vs. EXTERNAL STATIC PRESSURE					
CFM*	**0.10**	**0.20**	**0.30**	**0.40**	**0.50**	**0.60**
200	326	232	-	-	-	-
400	530	450	450	404	-	-
600	596	596	616	596	596	653
800	739	770	800	815	829	871
1000	924	949	974	1056	1033	1044
1200	1100	1111	1163	1213	1232	1261
1400	1307	1343	1403	1436	1436	1477
1600	1540	1548	1578	1608	1615	1637
1800	1715	1763	1783	1803	1835	1854
2000	1936	1984	2008	2026	2060	2072
2200	2151	2139	2125	2105	2089	2083

*CFM value selected in thermostat *Advanced Settings*

Table 2 HEATING PERFORMANCE DATA*				
	MBH at Entering Water Temperature			
CFM	**120**	**130**	**140**	**150**
600	20.1	26.2	30.3	36.1
800	26.1	30.9	38.0	43.2
1000	29.3	34.8	43.3	51.3
1200	32.0	41.2	50.1	58.9
1400	34.3	44.5	54.5.	64.3
1600	39.9	50.3	60.8	69.1

*At 65° entering air temperature and flow rates listed in Table 3.

Table 3 WATER FLOW AND PRESSURE DROP		
Heating Capacity, MBH	**Minimum Water Flow, GPM**	**Coil Water Pressure Drop, feet w.c.**
20 - 25	2	0.16
26 – 35	3	0.33
36 – 45	4	0.54
46 – 55	5	0.81
56 - 70	6	1.11

Table 4 ELECTRICAL RATINGS*		
Blower CFM	**Amps****	**Watts**
400	0.2	20
800	1.3	160
1000	1.7	213
1200	2.8	302
1400	3.8	453
1600	4.9	588
1800	6.6	754
2000	10.0	856
2200	10.5	895
Circulating Pump***	0.52	85

*All at 0.4" external static pressure, except 400 CFM measured at 0.04”.
**At 115V
***For Taco 006

EQUIPMENT PLACEMENT & SIZING

Damper and Air Handler Locations and Duct Requirements

The NightBreeze air handler may be installed in any location, but should be as close to the damper as possible to minimize pressure and thermal losses. The damper mounts directly over the ceiling return grille, which should be located in an accessible location over a hallway, since access to the damper is required for filter replacement. Refer to *Dimensions and Clearances* for air handler and damper space and clearance requirements.

Outside Air Intake Location

Outside air must be ducted from an intake location to the damper as shown in Figure 1. Use either a gable-mounted louver, a dormer vent, or false chimney with suitable vent cap for the outside air intake. Refer to Table 5 for required free area.

Duct and Register Sizing

The recommended airflow rate for ventilation cooling is 0.6 CFM per ft^2 of floor area. Ducts should be sized using the Manual J airflow rate or 0.6 CFM per ft^2 , whichever is greater. Recommended minimum sizes for outside air and return duct mains are indicated in Table 5. Size branch ducts and registers by apportioning the recommended ventilation rate from the table according to room or zone load, and using a maximum external static pressure of 0.3" w.c.

Figure 1 - Air Handler and Damper Configuration

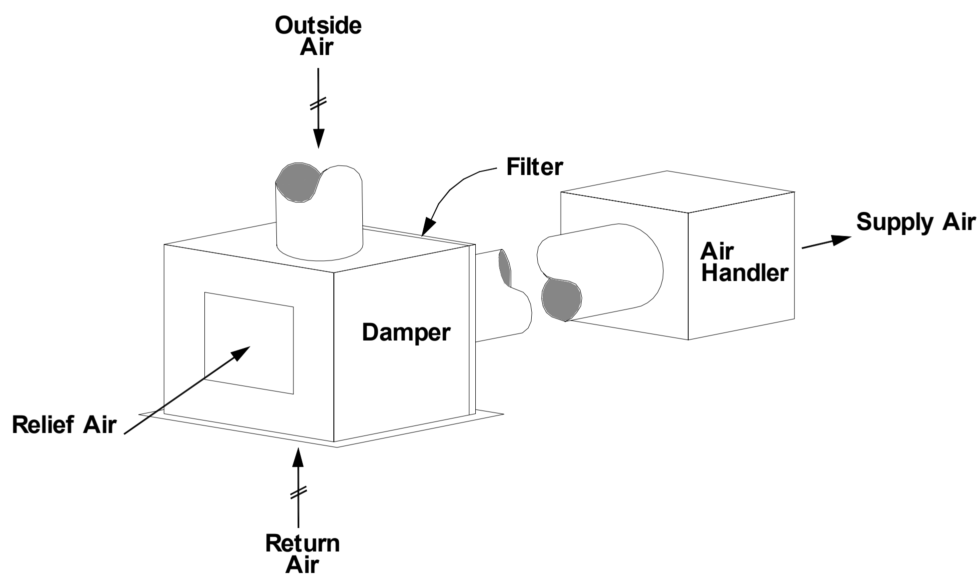


Table 5 DUCT SIZING RECOMMENDATIONS			
House Floor Area	**Recommended Maximum Ventilation Airflow**	**Minimum Duct Size**	**Vent Intake Minimum Free Area, ft²**
Up to1400 ft²	800 CFM	14"	1.00
1400 - 1800 ft²	1000 CFM	16"	1.25
1800 - 2200 ft²	1300 CFM	18"	1.63
2200 - 2600 ft²	1600 CFM	20"	2.00
2600 - 3000 ft²	1800 CFM	20"	2.25

Dimensions and Clearances

Dimensions for the air handler are shown in Figure 2 and for the damper in Figure 3. Provide at least 36" clearance to the air handler access panel to allow for servicing the blower and coil, and access to the damper where the drive motor is mounted and to the gravity damper flap. Zero clearance is permitted to all other air handler and damper surfaces.

Figure 2 – Air Handler Dimensions

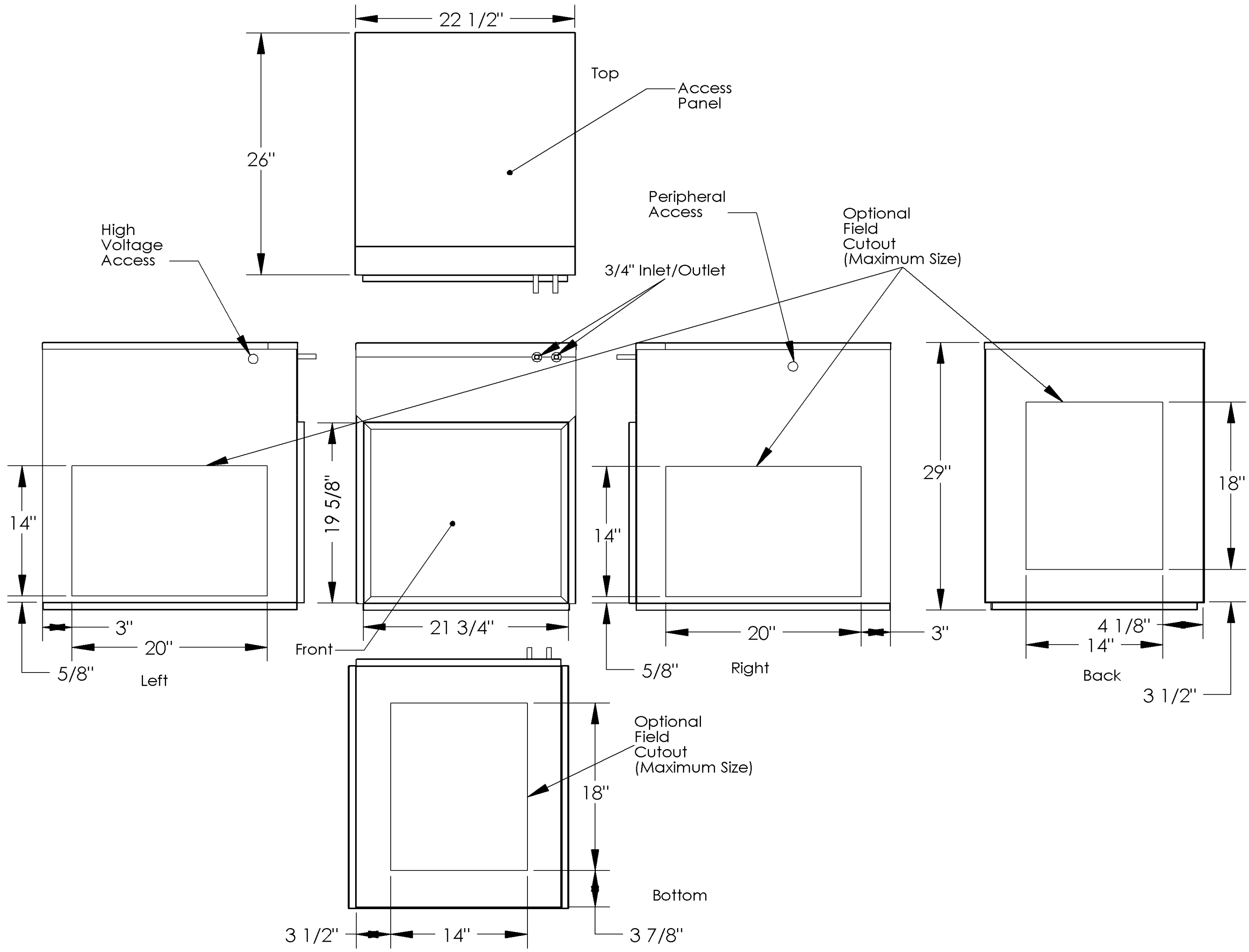
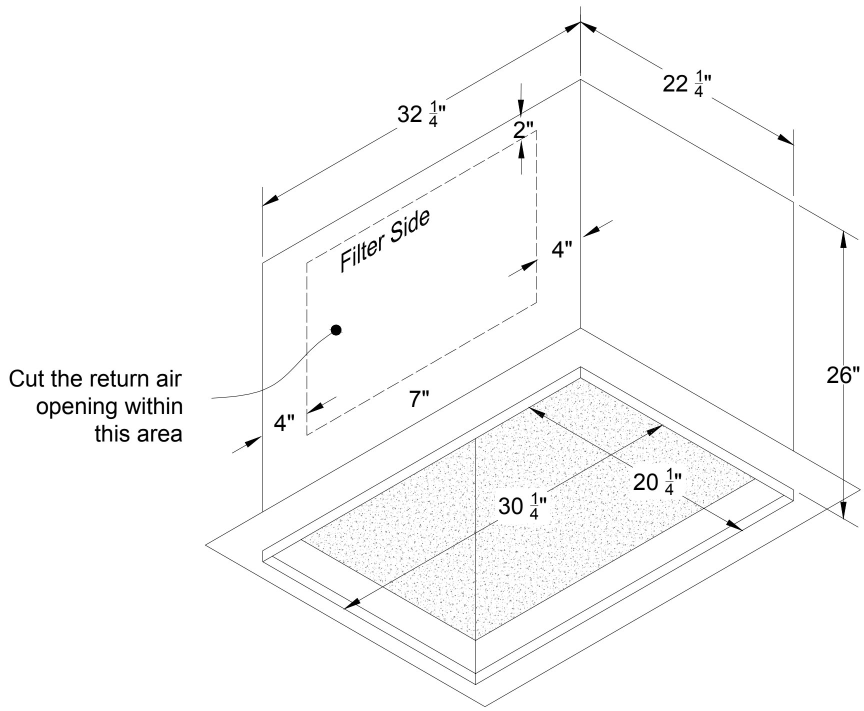
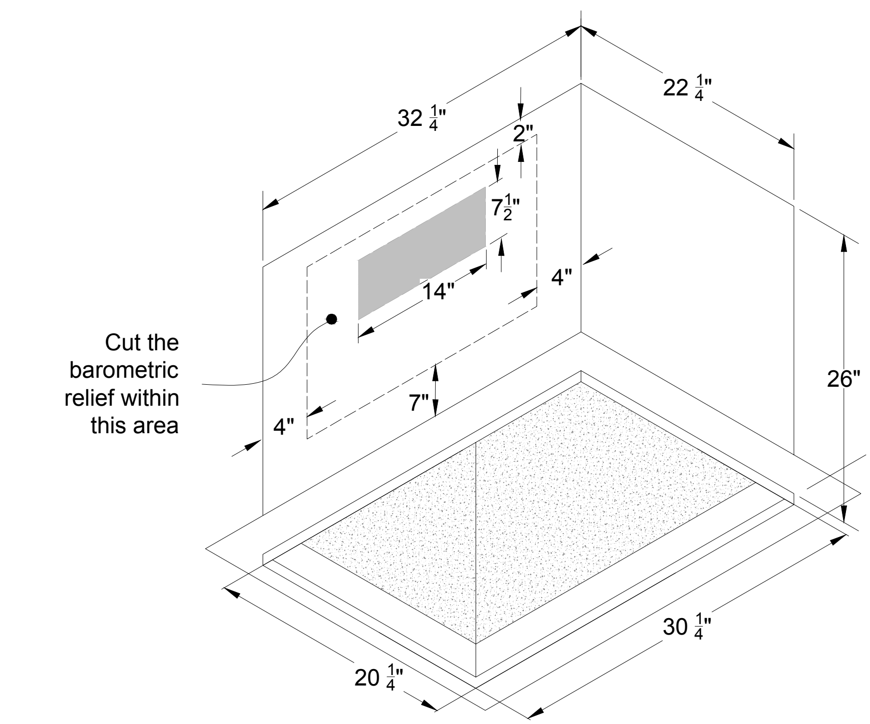


Figure 3 – Damper Dimensions





Damper Placement

The outside air damper should be located in the attic, central to supply air registers, and immediately above the return air grille. Consult the manufacturer's representative for alternate mounting configurations. The damper requires two duct connections, one to the air handler and one to the outside air intake. If the damper is not installed in a space that is vented to outdoors, a relief duct will also be required. See Figure 1.

Cooling Coil and Condenser Sizing

Air conditioners should be sized in accordance with ACCA Manuals J and S. Depending upon climate, house design, and control settings, NightBreeze may reduce cooling load by more than 5 Btu per square foot, thereby providing an extra safety margin on air conditioner sizing.

The NightBreeze air handler can be used with up to a 5 ton air conditioner. NightBreeze generally requires higher airflow rates for ventilation cooling than for air conditioning, so cooling coils should be oversized by at least one ton to minimize pressure drop (and fan energy use) while the system is ventilating. The larger coil will also improve air conditioner performance. The condensing unit should be located as close as possible to the air handler; refer to condenser manufacturer's instructions for refrigerant line sizing.

Table 6
COOLING COIL SIZING

Condenser Size	Recommended Minimum Cooling Coil Size
2 tons	3½ ton
3 tons	4 ton
3½ - 5 tons	5 ton

Return/Relief Air

To assure ventilation cooling performance as well as performance of heating and cooling systems, transfer ducts or grilles must be installed to provide return/relief air to any spaces that can be isolated from the return air grille by closed doors. This may apply to any space with more than 100 CFM of supply air. Undercut doors can usually supply up to 100 CFM.

Heat Source Sizing and Water Temperature

The heat source must have sufficient heating capacity to accommodate the space heating load. For combined systems that use the same heat source for space heating and domestic hot water, the heat source must be sized for both loads. The heat source must be also be capable of delivering hot water at the required temperature (see Table 2). For combined systems, If the temperature requirement exceeds 130°F a hot water mixing valve or other means of limiting domestic hot water temperature must be provided to prevent scalding.

Hot Water Piping

Locating the air handler close to the water heater or boiler will save piping costs and reduce pipe heat loss. Increase pipe size from ¾" to 1" if the total equivalent length of piping exceeds 50 feet. Insulate all piping with ¾" thick molded foam insulation. Observe the flow direction indicated at the air handler water connections. Refer to water heater/boiler manufacturer instructions for connections. The heat source should be capable of producing at least 140°F water. Refer to Table 3 for heating ratings.

Control Placement

Outdoor Temperature Sensor: Proper placement of the outdoor temperature sensor is very important to assure proper control operation and temperature readings. Always locate it on the north side of the building where it will be shaded from direct sunlight. Avoid placement above a roof or adjacent to a west or northwest facing wall, or anywhere where hot air collects.

Thermostat: Locate the wall display unit (thermostat) on an interior wall, near the return air grille. For two story residences install the thermostat on the second floor.

INSTALLATION

Preparation and Scheduling

<u>Prior to Rough-In</u>

1. Select and coordinate mounting locations for air handler and damper.
2. Select and coordinate size and location for the outside air intake with the builder/architect.
3. Determine main duct sizes and how they will be routed.
4. Size branch ducting using ACCA Manual D or other recognized methods.
5. Verify the heat source has sufficient capacity to meet all heating needs (space heating, plus domestic hot water if a combined system is used).
6. Prepare a piping diagram for connections between the heat source and the air handler(s).
7. Select location for pump and pump relay.
8. Coordinate piping and wiring requirements with plumber and electrician.

<u>Rough-In</u>

1. Install air handler, damper box, and ducting. Note that the damper assembly may be removed from the damper box during construction to prevent it from being coated by texture and paint.
2. Install control wiring from the air handler to the thermostat, outdoor sensor, damper, and pump locations.
3. Install or coordinate hot water piping between heat source, pump, and air handler.
4. Install refrigerant lines and control wiring between air handler and condensing unit location.
5. Coordinate power wiring to air handler and pump with electrician.

<u>Finish</u>

1. Mount damper mechanism in damper box and connect wiring.
2. Install and wire thermostat and outdoor temperature sensor.
3. Install and wire pump and pump relay.
4. Install condensing unit (optional).
5. Verify water, refrigerant, and electrical connections.
6. Install air filter.
7. Test system.

Air Handler

Install the air handler on decking in an accessible attic or 2nd floor mechanical space. Conform to local codes for access and condensate drainage. Except for the access side, the cabinet is zero clearance and there are no combustion air or venting requirements. To minimize noise at the return grille, connect the air handler to the damper using at least 5' of appropriate size flex duct (see Duct Sizing Recommendations table). The air handler may either be mounted in a horizontal, up-flow, or down-flow configuration. Optional side and bottom cut-outs may be made for installation in side or bottom return applications (see Fig. 2).

Damper

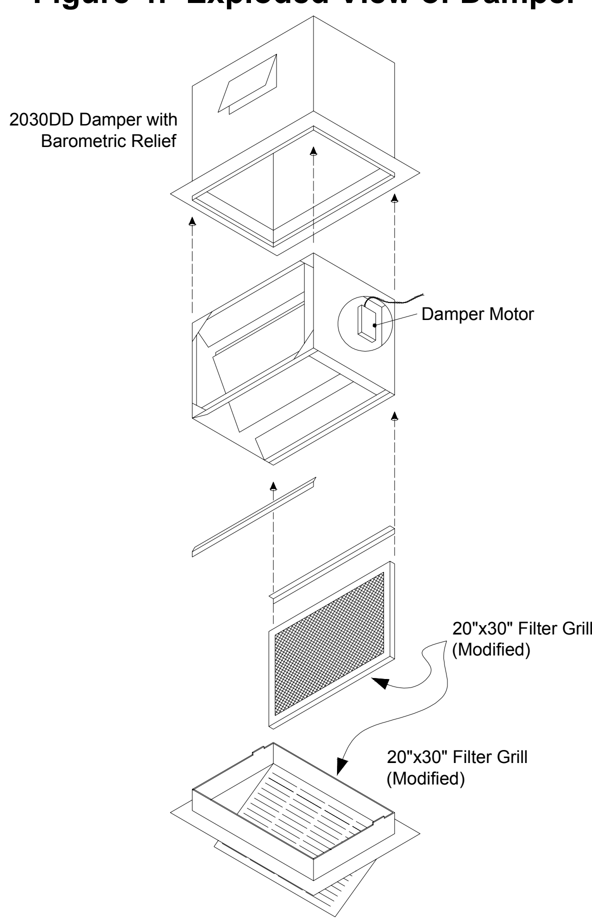
An exploded view of the damper is provided in Figure 4. The damper mounts immediately above the return air grille with the flanged side down. Up to 18" round openings may be cut for duct connections (see Fig. 3 for locations). For ducts larger than 18" either use oval collars or provide appropriate adapters. Refer to Table 4 for sizing outside air ducting; the duct connecting to damper to the air handler must be the same size.

The side of the damper opposite the barometric relief opening connects to the air handler. The top opening connects to the outside air intake. Note that the damper has only one correct installed position. The damper mechanism may be removed from its duct board enclosure and stored in a safe place to avoid damage during construction. Provide a 20" x 30" hinged filter grille for access to the filter, which mounts in a vertical slot inside the damper. The filter grille flange must be notched to allow the filter to slide in and out freely. The damper accommodates a 20" x 30" x 1" filter. 3M Filtrete® 1000 or 1250 filters, or equivalent are recommended.

IMPORTANT

Do not move damper blade manually. This will damage motor/gear assembly.

Figure 4: Exploded View of Damper



Wiring

Air Handler Power: Install a disconnect switch at the air handler. Connect hot, neutral, and ground wires to the black, white, and green wires in the air handler power wiring box. Provide appropriate strain relief or conduit as required by code. Refer to Figure 5.

> **IMPORTANT**
>
> All wiring shall be in accordance with local and national electrical codes.
>
> The blower motor is continuously powered. Allow 5 minutes after disconnecting power for capacitors to discharge before servicing the motor.

Controls: Use 4-conductor 18 gauge thermostat wire to connect the thermostat, outdoor temperature sensor, and damper to the air handler control terminals using the wiring conventions described in the following tables.

> **IMPORTANT**
>
> Controls utilize digital communications. Use only the thermostat provided with the system (TS36). Do not attempt to operate the system by jumpering control terminals, and **do not** connect controls to an external low voltage power source.

Table 7
THERMOSTAT WIRING

Thermostat (terminals labeled "CU")	Connecting Wire Color	Air Handler (terminals labeled "Thermostat")
-	Green	Gnd
+	Red	+V
C	Black or Blue	CK
D	White	DT

Table 8
OUTDOOR SENSOR WIRING

Outdoor Temperature Sensor	Connecting Wire Color	Air Handler (terminals labeled "Outside Sensor")
G	Green	Gnd
+V	Red	+V
C	Black or Blue	CK
D	White	DT

Table 9
DAMPER WIRING

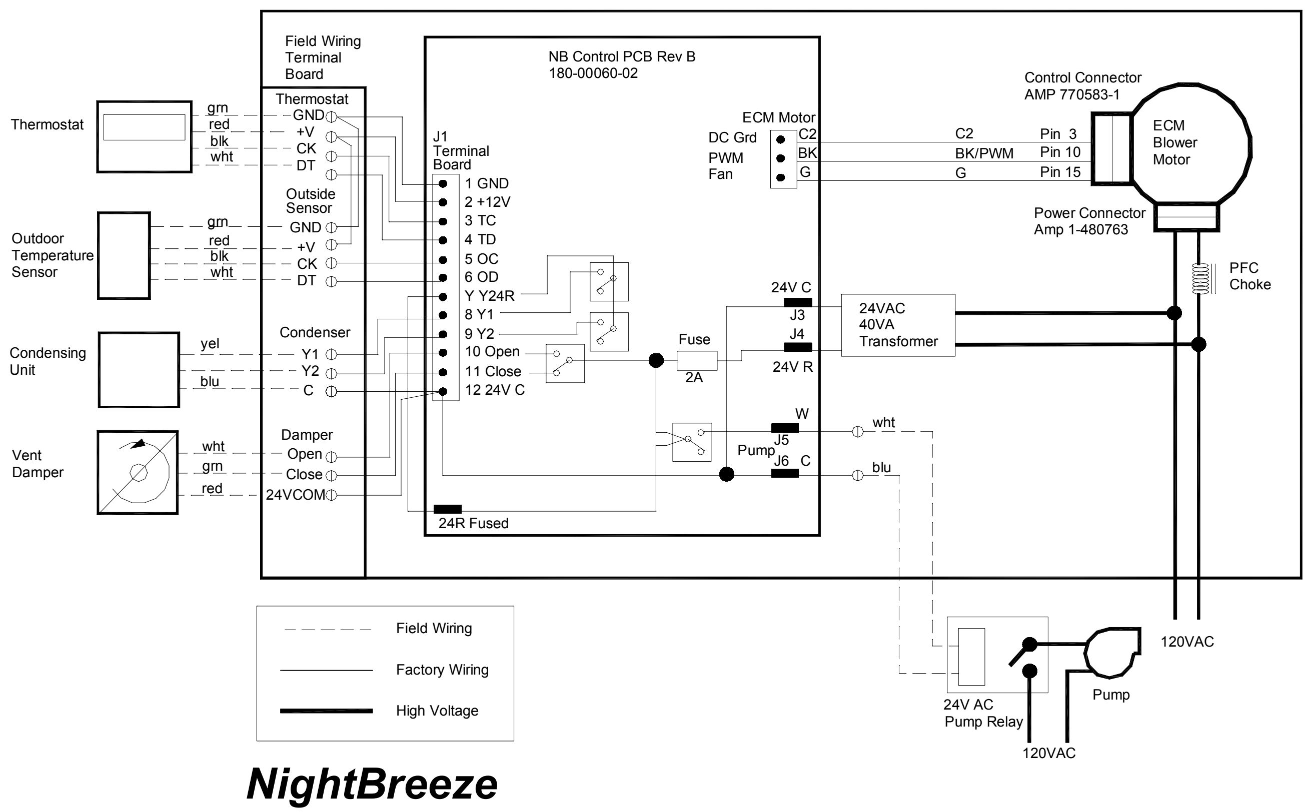
Damper (wire color)	Connecting Wire Color	Air Handler (terminals labeled "Damper")
White (3)	White	Open
Green (2)	Green	Close
Red (1)	Red	Com

Pump Power and Relay: Install a junction box near the pump for mounting the pump relay. Wire the pump to the pump relay as shown in Fig. 4, and connect the low voltage control wire from the air handler to the low voltage inputs to the relay. The air handler pump control terminal block is located apart from the other terminals just below the transformer.

Condenser Wiring: Connect the condenser control wires to the C and Y1 terminals at the air handler terminal block. The output from these terminals is 24 VAC (not dry contact).

Note: This model is not configured for a two speed condenser - Y2 is not operative.

Figure 4 - Wiring Diagram



Pump Selection and Installation

Because of the wide variation in flow and pressure encountered in different installations, a pump is not provided with the NightBreeze system. The pump must be sized for the design flow (determined using Table 3) and the total system pressure drop, including the heat source, heating coil (from Table 3), and piping. Especially when using tankless, or instantaneous, water heaters be sure to consult manufacturer's literature for pump sizing for combined heating applications.

A pump relay is provided in the NightBreeze parts kit. The relay should be located close to the pump and wired as shown in Figure 4.

Piping

The air handler coil may be connected to either a potable water system or a closed-loop pressurized system. Install 3/4" copper or PEX (if approved) piping between the water heater or boiler and the air handler (1" is recommended if the total piping length exceeds 100 ft.) Provide an air vent near the fan coil to remove air from the piping as needed. To facilitate flushing the piping and future service needs, provide isolation valves and a drain at the connections to the hot water source, and unions at the connections to the air handler.

Figure 5 provides an example of how piping should be installed for most tankless water heaters. Tempering valves are required whenever the hot water temperature required for the air handler exceeds 130°F (see Table 2). Be sure to select a tankless water heater model that is approved by the manufacturer for combined heating/domestic water heating applications.

IMPORTANT!

Avoid running piping in locations where it could potentially freeze, or provide suitable freeze protection.

Insulate all piping with ¾" or thicker molded foam pipe insulation.

Flush piping to remove contaminants prior to connecting to domestic hot water system.

CONTROL SETUP

Advanced Settings

IMPORTANT!

Airflow rates and other permanent control settings must be completed before turning the system over to the owner.

Follow these instructions carefully:

1. Press the *Mode* button on the thermostat until *Off* is displayed.
2. Hold down the two arrow buttons to the right of the display simultaneously until the *Advanced Settings* menu appears.
3. Use the up/down arrow buttons to select the menu item and the - / + buttons to adjust the settings. The table below explains each setting.
4. When finished, press the button marked *Done*.

Comfort Range Settings: The NightBreeze system regulates the amount of ventilation cooling provided by automatically varying both the indoor temperature at which ventilation cooling is terminated and the airflow rate. There are 10 different comfort settings to meet the needs of the owner. The default setting is 0. The control strategy behind the warmest (+5), coolest (-5), and average (0) settings is as follows:

> ***Setting = -5***: The system always attempts to vent the house down to the low limit setting.
>
> ***Setting = +5***: The system attempts to provide just enough ventilation cooling so that the house will not be warmer than the high limit (air conditioner) setting.
>
> ***Setting = 0***: The system attempts to maintain the indoor temperature range between the low limit and high limit settings.

Table 10
ADVANCED CONTROL SETTINGS

Menu Item	Description	Recommended Setting
Comfort Adjust	Preferred comfort range (-5 to +5). See **Comfort Range Settings** for explanation)	0 (default)
Vent Delta Temp	Indoor-outdoor temperature difference at which ventilation cooling will be initiated, °F. (0-9)	5 (default)
Tout Offset	Outdoor temperature sensor calibration, °F. (-9 to +9)	0 or calibrate
Tin Offset	Indoor temperature sensor calibration, °F. (-9 to +9)	0 or calibrate
AC Mode	Air conditioner operating mode (Standard, Precool, or None)	*Standard* if AC installed (default) *None* if no AC installed *Precool* (disabled)
AC on Delay	Time delay between condensing unit cycles, minutes. (0 to 5)	0 if condensing unit has built-in time delay, or 5 if it doesn't
Man Fan Time	Length of time fan will run when the *Fan* button is pressed, hours. (0 to 4)	1 (default)
AC Fan CFM	Airflow for air conditioner operation, CFM (100 to 2100)	See Table 12
Ventilation Rate	Average hourly airflow rate for heating mode fresh air ventilation, CFM. (0 to 95)	See Table 11
Vent Fan CFM	Maximum airflow for ventilation cooling, CFM (100 to 2200)	See Table 11
Heat Fan CFM	Maximum fan speed for heating operation, CFM. (100 to 2200)	See Table 12
Man Fan CFM	Maximum fan speed for manual fan operation	See Table 11

Sensor Calibrations: Both the indoor (thermostat) and outdoor air temperature sensors should be calibrated using advanced control settings at time of installation. To calibrate the sensors use an accurate handheld digital thermometer to measure air temperature in close proximity to the thermostat and the outdoor temperature sensor. If the measured temperature is lower than the temperature displayed by the thermostat, enter a negative offset, and vice versa. For example, if the thermostat reads 70° indoor temperature and the measured temperature is 72°, enter a +2 next to *Tin Offset*. Be sure to allow adequate time for the handheld thermometer to equilibrate to ambient temperatures before taking readings.

Airflow Settings: Set airflow rates in *Advanced Settings* to values in Tables 11 and 12.

IMPORTANT!

Proper airflow settings are necessary to insure correct system operation and optimal performance.

Table 11 RECOMMENDED VENTILATION RATE SETTINGS			
House Size (ft²)	**Vent Fan CFM**	**Manual Fan CFM**	**Heating Ventilation Rate**
Up to 1400	800	600	15 CFM / bedroom + 15 CFM
1400 - 1800	1000	800	15 CFM / bedroom + 15 CFM
1800 - 2200	1300	1000	15 CFM / bedroom + 15 CFM
2200 - 2600	1600	1200	15 CFM / bedroom + 15 CFM
2600 - 3000	1800	1400	15 CFM / bedroom + 15 CFM

Table 12 HEATING AND COOLING CFM SETTINGS				
HEATING			**COOLING**	
Heating Load (Btu/hr)	**Heat Fan CFM**		**AC Size (tons)**	**AC Fan CFM**
20,000	600		1-1/2	600
30,000	800		2	800
40,000	1000		2-1/2	1000
50,000	1200		3	1200
60,000	1400		4	1600
70,000	1600		5	2000

When all advanced settings have been entered, press *Done.*

Basic User Settings

Setting the Clock: If the thermostat clock does not display the correct time, select *Off* mode and press the *Clock* button. Use the ← and → buttons to position the cursor under the time or date digits you want to change, and use the up/down buttons to the right of the display to change the setting.

Temperature Settings: Refer to the Owner's Manual for information on changing temperature settings, and/or use the *Help* button.

Note: If the outside temperature displays 00, disconnect and restore power to the air handler. This will occur if the thermostat is removed from its wall plate and replaced without first cutting power.

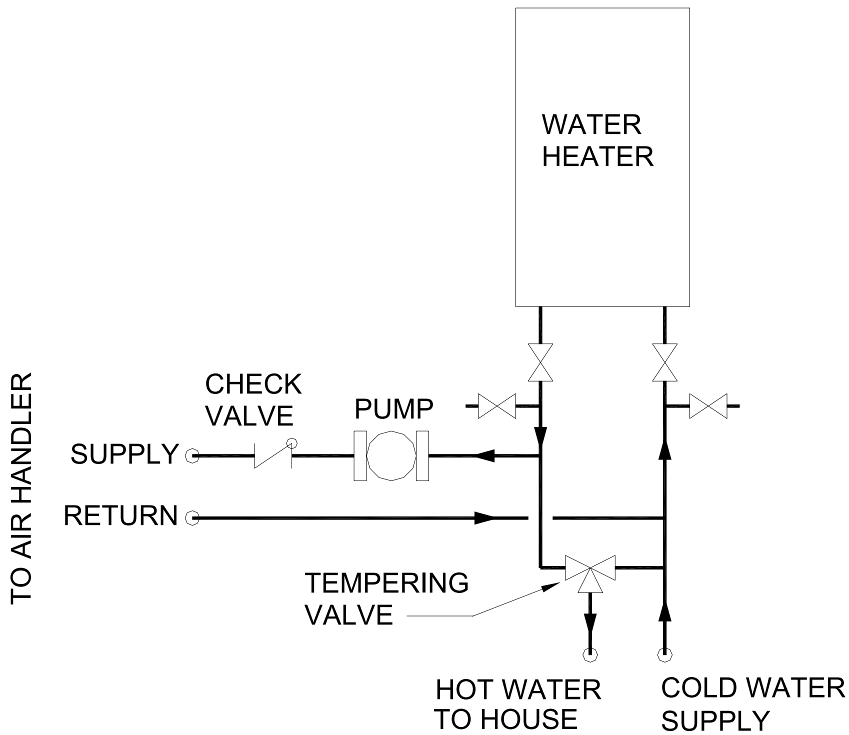
STARTUP

1. Apply power to the air handler.
2. Verify that the thermostat display is lighted.
3. Follow instructions in **CONTROL SETUP** for configuring control settings.
4. Verify that the hot water source (boiler or water heater) is operational. Refer to Table 2 for recommended water temperature settings.

> **IMPORTANT!**
>
> For combined systems using water temperature settings greater than 130°F provide a suitable mixing valve to prevent potential scalding.

5. Purge all air from piping.
6. At the thermostat select *Heat* mode and press the *Up* button until the set temperature exceeds the indoor temperature by about 2°.
7. The Fan and Heat indicator lights should light, and the fan and pump should start. Verify that hot water is circulating to the heating coil.
8. If air conditioning is installed, verify condenser operation by selecting *Cool* mode and activate cooling by pressing the *Down* button until the set temperature is about 2° lower than the indoor temperature.
9. The Fan and A/C lights should light. Verify that the condenser is operating.
10. Verify damper operation by pressing the *Fan* button (from either *Heat* or *Cool* mode) twice. The squiggly arrow will indicate that the system is bringing in outdoor air (a circular arrow indicates that air is being recirculated). The *Fan* light should light; visually inspect the damper through the relief opening to insure the damper changes position to admit outdoor air.
11. Refer to **TROUBLESHOOTING** if the system fails to operate properly.

Figure 5: Piping Example for Tankless Water Heaters



TROUBLESHOOTING

No display on thermostat

Verify power at air handler

Verify control wiring between air handler & thermostat

Is the red LED on the control module blinking?

No: Replace control module

Yes: Replace thermostat

Blower works but system will not heat

Select Heating mode and raise setting above room temperature

Verify *Heat* LED at thermostat is lighted

Check power at pump

Pump has power?

No: Replace control module

Yes: Purge air from lines or replace pump as needed

Display works but blower will not run

Verify both connectors are plugged into blower motor

Set *Max Fan* in *Advanced Settings* to "8" and press Fan button (in Heat or Cool modes)

115V between black and white leads at 5 pin motor connector?

No: Replace PFC choke

Yes: Replace control module

Blower still won't run

Replace motor controller

Damper doesn't operate

Press Fan button until squiggly arrow appears

Voltage across 24V common and "Open" terminal at control module?

No: Replace control module

Yes: Replace damper motor

Alternatives To Compressor Cooling Project

Advanced Control Functional Specification

PIER Contract #500-98-024

Date Completed: May 15, 2002

Presented to: Phillip Spartz
California Energy Commission

Prepared by: David Springer
Leo Rainer
Michael Kuhlmann

Table of Contents

Attachments

1 Overview

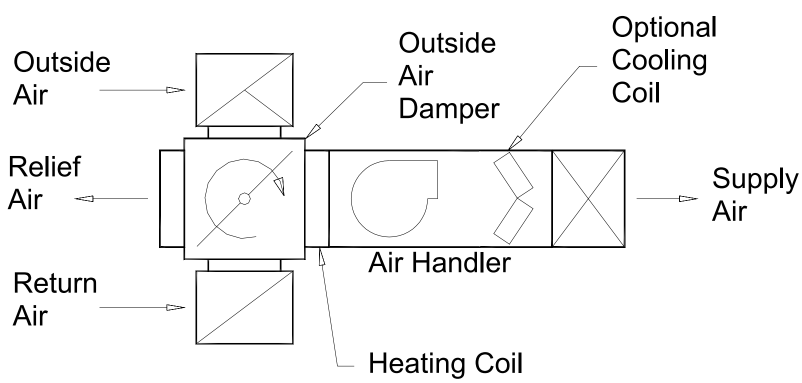
This specification defines physical and operational criteria for an advanced control that operates an integrated system that provides night ventilation cooling system, heating , air conditioning, and fresh air ventilation. This document includes both firmware and hardware specifications for the production model of the control developed by Davis Energy Group and RCS, respectively. Controls are ready to market and have been trademarked "NightBreeze".

The control consists of two main components, a wall display unit, or thermostat, and a control unit that are interfaced by a digital communications link. Each of these components includes a microprocessor programmed primarily in 'C' to meet this specific application.

2 Controlled Components

Components controlled by the include a hot water furnace (air handler) and fan, and an outside air damper as shown in Figure 1. The fan is driven by a General Electric ICM2 variable speed motor that is programmed to deliver a fixed airflow at a given demand setting. The damper shown in Figure 1 is representative of a ZTECH SmartVent Model 2030DD. Optionally the control will also operate a split system air conditioning condenser (connected to the cooling coil).

Figure 1: Controlled Components

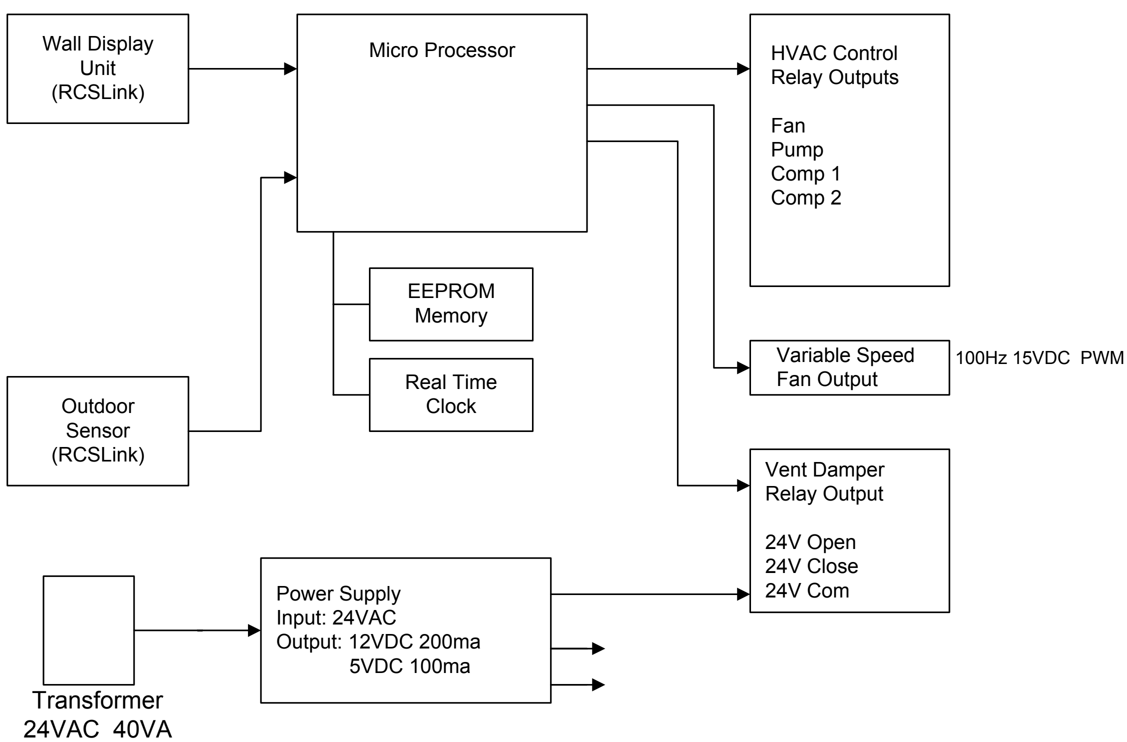


3 Prototype Control Platform

The RCS TS36 wall display unit was selected as the development platform for the prototype "thermostat". The wall display unit (WDU) includes a 2-5/8" x 1-3/8" (128 x 64 pixel) LCD display, four push-buttons mounted below the display, and two (up-down) buttons to the right of the display. Four LED's to the left of the display provide status indication. Labels for the four lower buttons are programmable and are arrayed along the bottom of the LCD screen. The screen display and control logic are managed by Philips P89C51RC 8-bit microcontroller, which has 512 kbytes of RAM and 32 kBytes of flash memory. The microcontroller is located on the TS36 PC board. The TS36 is pictured in Figures 3-8.

Unlike conventional thermostats, the WDU does not provide direct switching. Instead it connects to a separate microprocessor control unit which contains relays for switching the furnace gas valve, fan, damper, and compressor. RCS developed a PC board specifically for this application, identified by the part number NightBreeeze 180-00060-02 Rev B. This board uses a Microchip PIC16C63 microprocessor and is powered by a solid state switching power supply that is integral with the board. An outdoor temperature sensor connects to the control unit, which can also accept optional inputs from a second thermostat and provide optional outputs for zone dampers and a variable speed fan. A four-wire digital bus provides communications between the thermostat and the outdoor temperature sensor and the control board. A block diagram of the WDU, control unit, and other components is shown in Figure 2. A wiring diagram is provided as Attachment 1.

Figure 2: Block Diagram of Night Vent Control System

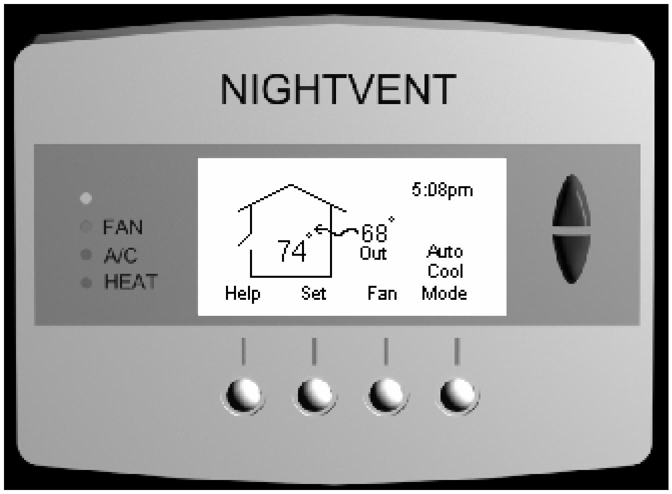


4 User Interface Screens

Wall display unit programming incorporates bitmap images of display screens for each user input mode, including *cooling*, *heating*, *vacation*, and *off*. Screens also facilitate changing heating and cooling setpoints, and guide the user through the other input options. A menu tree listing user interface screens for each operating mode and corresponding bitmap images is provided in the appendix. Figure 3 displays the *Auto Cool* screen with ventilation active.

Indoor and outdoor temperatures are displayed. The window in the house icon opens when it is cooler outside than in. The arrow icon is used to indicate whether the system is drawing in outside air or recirculating it, based on damper position.

Figure 3: Prototype User Interface Display, Cooling Mode



5 Basic Thermostat/Control Functions

5.1 Ventilation Cooling

The control operates to provide ventilation cooling under the following circumstances:

- Thermostat set in cooling mode
- Outdoor temperature lower than indoor temperature (by set differential)
- Indoor temperature greater than vent target temperature

Objectives of this control mode are to provide sufficient ventilation cooling to significantly offset or eliminate air conditioner operation while ensuring comfort by preventing overcooling and minimizing fan energy use. This is accomplished by using a two-day history of measured air temperatures to predict the outdoor and indoor temperatures for the next day. These predictions are then used to establish an indoor "vent target" temperature, and to set the speed, or airflow rate, at which the system will ventilate. Indoor temperature predictions are displayed by the shaded "comfort bar" shown in Figures 4 and 5.

The user adjusts the low limit temperature and high limit temperature (air conditioner setpoint) using the up/down buttons as shown in Figures 4 and 5 (see arrow above bar). Depending upon the temperature history, the comfort bar will "follow" the settings, and will center itself between the low and high settings[1]. When the high and low settings are changed,

[1] The comfort bar will not go below the predicted low nighttime temperature because the outdoor minimum temperature limits the temperature that house can ventilate to.

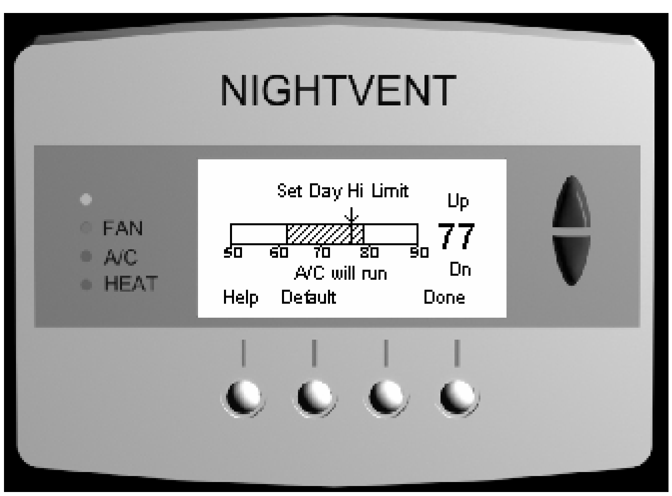
control logic instantaneously recalculates the predicted indoor temperatures that would result from these settings and resets the comfort bar.

5.2 Refrigerant (Compressor) Cooling

The temperature at which the air conditioner will start is set on the wall display as shown in Figure 5. The up/down arrows are used to adjust the temperature setting, and the vertical line (with arrow above) shows if the temperature setting will result in air conditioner operation given the maximum indoor temperature predicted by the control (right side of shaded bar). Unlike conventional thermostats, no temperature scheduling functions will be provided since they would interfere with night ventilation cooling strategies. The control will incorporate other typical cooling functions such as a 5 minute time delay to prevent compressor short cycling, and a setpoint differential to minimize hysteresis.

Figure 4: Display for Setting Cooling Low Limit Temperature

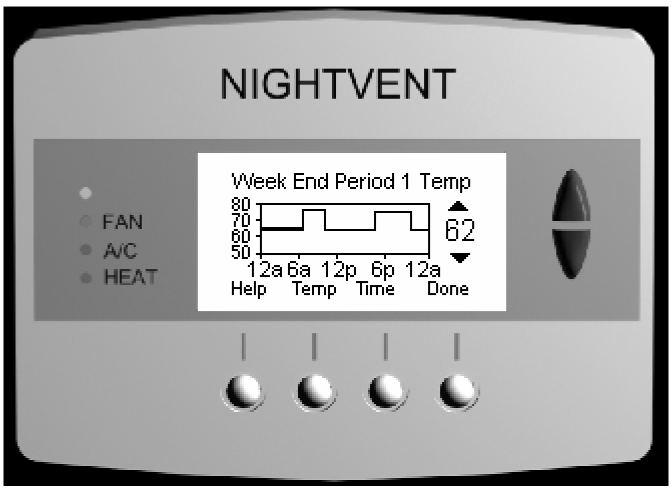
Figure 5: Display for Setting Air Conditioner Temperature



5.3 Heating

To avoid the need for a separate heating thermostat the control includes the capability to operate the variable speed forced-air hydronic heating system. User interface soft-key capabilities provide a simplified approach to setting heating temperatures and schedules, as shown in Figure 6. The temperature graph displays scheduled temperatures for four time periods. Temperatures and schedule times can be selected using the “Temp” and “Time” buttons and modified using the up/down arrows. Pressing “Temp” will cause the first horizontal line to flash. Pressing the up/down buttons shifts this line up or down corresponding to the selected temperature. The vertical time lines respond in the same fashion. Repeatedly pressing the *Temp* or *Time* buttons advances to the next period.

Figure 6: Display for Adjusting Heating Setpoints and Schedule



5.4 Fresh Air Ventilation

In cooling mode fresh air is provided during nighttime hours while the system is cooling the house. In heating mode the system can be programmed to provide the exact amount of ventilation prescribed by ASHRAE 62-89, or other user preference.

5.5 Temperature Override, Vacation Mode, Clock, and Advanced Settings

To satisfy the need for temporary (override) temperature settings, control functions are provided to allow the operator to set heating and air conditioner temperatures for a period of time that can also be selected by the operator (Figure 7). These settings are accessed by pressing the up/down buttons.

In “vacation” mode high and low temperature limits can be set and the control will automatically change from heating to cooling mode as needed, and heating, air conditioning, and ventilation cooling will be applied to maintain the indoor temperature between these settings (see Figure 8).

When the user selects *Off* mode, menu options for clock settings (*Clock*) and advanced settings (*Adv*) appear. The clock setting is used to adjust the thermostat time, which is used by the control to operate the heating schedule. Advanced settings are primarily for use by the installer or technician to adjust heating and cooling setpoint differentials, minimum heating and cooling run times, air conditioner startup time delay, and system configuration (A/C or no A/C, one or two zone). A list of advanced settings is provided in Attachment 3.

Descriptions of all commands are provided in the menu tree in Attachment 2.

Figure 7: Display for Temperature Override

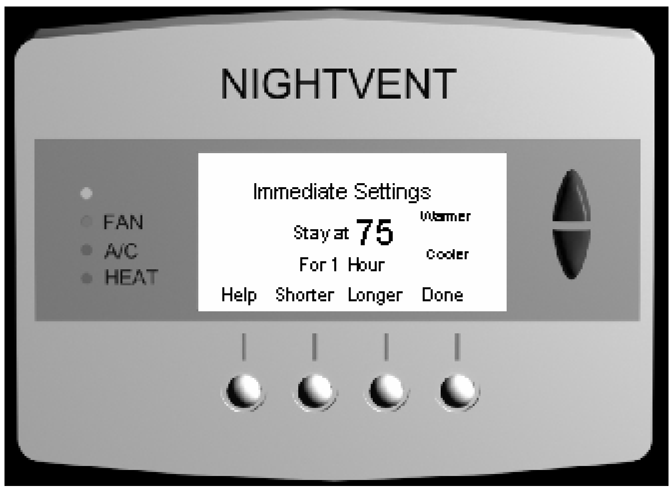
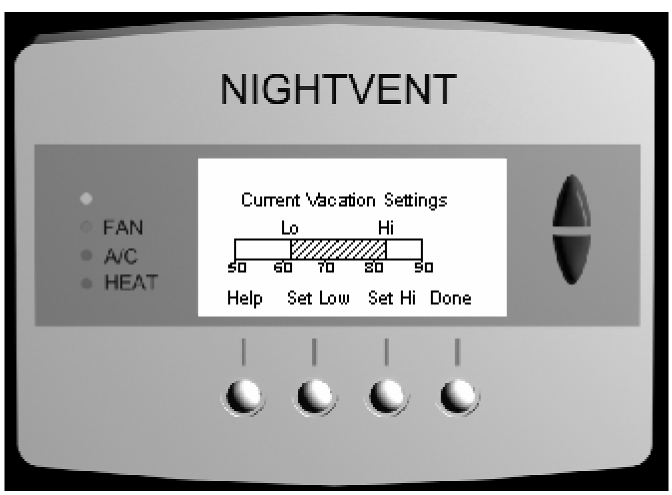


Figure 8: Display for Vacation Mode Settings



6 Inputs and Outputs

6.1 User Inputs

"Long-term" or permanent user inputs include:

- Clock settings (date and time)
- Ventilation cooling low limit temperature
- Air conditioner setpoint temperature (or ventilation cooling high limit)
- Heating schedule temperatures (4 per period, weekday/weekend periods)
- Heating schedule times (4 per period, weekday/weekend periods)
- Vacation mode low and high temperature limits

"Short-term" or transitory user inputs include:

- Fan on/off
- Short-term heating setting and duration
- Short-term cooling setting and duration

Embedded inputs that are intended to be inaccessible to the user are maintained in "Advanced Settings". These settings are accessed by holding down the up/down buttons simultaneously for 10 seconds. Advanced Settings menu options are listed in Attachment 3.

6.2 Sensor Inputs

Both outdoor and indoor temperatures are used to govern vent cooling operation. Indoor temperature is sensed at the thermostat. The outdoor temperature sensor is typically located in a shaded location, such as a north-facing wall.

6.3 Control Outputs

The control provides functional outputs for:

- Air handler fan on/off ("G") – 24VAC
- Fan motor speed control - 100 Hz 15VDC pulse width modulated (PWM) signal
- Outside air damper motor (open/closed) – 24VAC 3-wire
- Hydronic heating pump ("W") – 24VAC for switching 120VAC
- Air conditioner ("Y1" and "Y2") – 24VAC

7 Ventilation Cooling Control Logic

7.1 Control Strategy

The following general procedures are employed by the control logic to calculate control parameters each night at midnight:

1. Measure and store selected outdoor and indoor temperature values.
2. Use statistically-derived equations to calculate predicted outdoor minimum and maximum temperatures for the next day from measured outdoor and indoor temperatures.
3. Use statistically-derived equations to predict indoor minimum and maximum temperatures for the next day from predicted outdoor temperatures, and user thermostat settings
4. Use temperature predictions to establish the vent target temperature and the cooling demand for the current time period. The vent target temperature is greater than or equal to the minimum predicted outdoor temperature depending on weather conditions.
5. Calculate fan airflow from cooling demand.
6. Update displayed minimum and maximum outdoor temperatures (comfort bar).

Ventilation fan airflow rate is controlled as a linear function of the cooling demand and the maximum ventilation cooling setting made in advanced settings. Cooling demand ranges from 0 to 1. For example, if the maximum airflow is set to 1500 CFM and a demand of 0.5 is calculated based on predicted temperature conditions, the fan will receive a PWM signal corresponding to 750 CFM. Other outputs include 24VAC control signals to open the damper and to activate the fan motor[2].

Ventilation cooling starts (fan on, damper open, A/C off) whenever the outdoor temperature is lower than the indoor temperature by an amount equal to the vent delta-t and will continue until either the vent target temperature is reached, or the indoor-outdoor temperature differential no longer exists.

7.2 Ventilation Cooling Comfort Preference

If the occupant prefers warmer or cooler than typical indoor conditions, the comfort preference value entered in "Advanced Settings" can be used to adjust the vent target temperature. At a setting of –5 the vent target temperature equals the *low* setting, regardless of weather conditions. At a setting of +5 the control will apply a target temperature that is equal to the *high* setting minus the predicted indoor temperature range. At a setting of 0 the control will attempt to center the comfort bar (or range) between the *high* and *low* settings. Intermediate comfort settings result in corresponding positions of the comfort bar between the low and high settings.

---

[2] The fan motor needs both a "G" signal input to start and a PWM signal input to designate the CFM.

8 Air Conditioning Control Logic

The air conditioner is activated (G, PWM, and Y1 output signals) whenever the indoor temperature rises above the cooling setpoint established using the “high” setting or the short-term override setting. If the *AC On Delay* in Advanced Settings is set to any value greater than zero, the air conditioner and fan will only be activated after the specified delay period. If the outside air temperature falls below the indoor air temperature, the damper opens to provide an economizer cooling function. The minimum run time is 2 minutes.

9 Heating Mode and Fresh Air Ventilation Control Logic

9.1 Heating Operation

If the indoor temperature falls below the thermostat setpoint, the pump is activated (“W” signal), the fan is activated (“G” signal), and the fan operates at the prescribed speed (PWM signal). The airflow rate (based on fan speed) is proportional to the difference between the thermostat setpoint and the indoor temperature setting. Setpoint temperatures are modified according to the schedule entered by the user, or according to the user’s short-term (override) temperature setting.

9.2 Heating Mode Fresh Air Ventilation

If the ventilation rate[3] in *Advanced Settings* is greater than zero, the following control logic applies. If heating operates at any time during a given hour, the outside air damper opens and the control program accumulates the cubic feet of outside air that is delivered by the fan based on the fan speed and maximum heating airflow (set in *Advanced Settings*). As soon as the cumulative volume reaches the ventilation rate setting (times 60 minutes), the damper closes.

To prevent discomfort due to low supply air temperatures, the damper will close if the estimated supply air temperature falls below 100°F. The supply air temperature is estimated from the fan speed, outdoor air temperature, and assumed heating coil performance.

If no heating has occurred during the hour, or of insufficient heating has occurred to enable fresh air volume requirements to be met, the control calculates how many minutes of operation will be required to deliver the specified volume of fresh air. The fan will then operate at minimum speed and the damper will open for the number of minutes calculated to fulfill the ventilation requirement just prior to the end of the hour. Also, if the outdoor temperature is below 45°F, the heating pump is automatically activated to preheat ventilation air. If the outdoor temperature falls below 35°F, fresh air ventilation is disabled to prevent freezing of the heating coil.

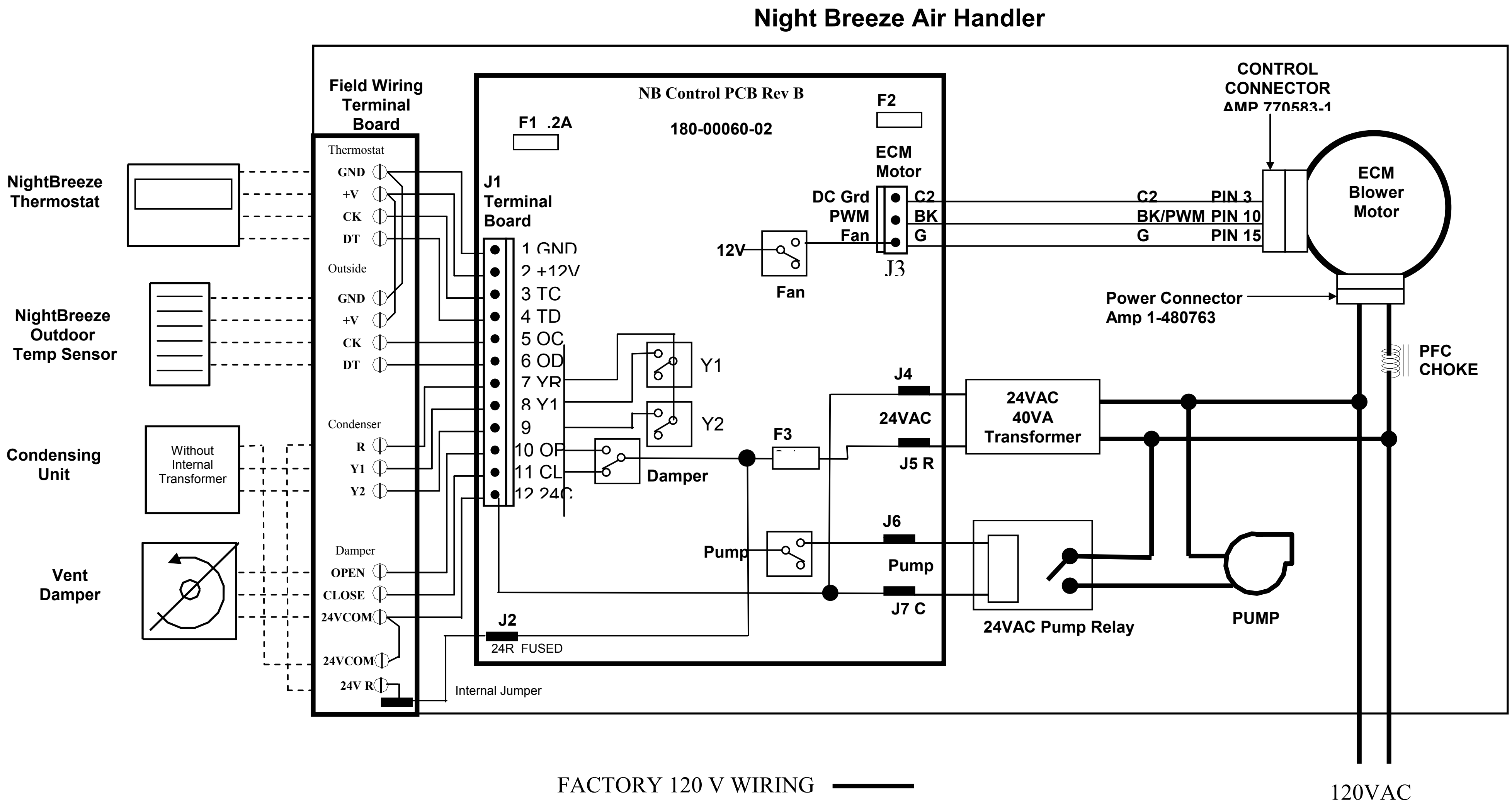
10 Vacation Mode

If the indoor temperature falls below the low temperature setting the heating system is activated. Operation is similar to that described in Section 9 except that the fresh air

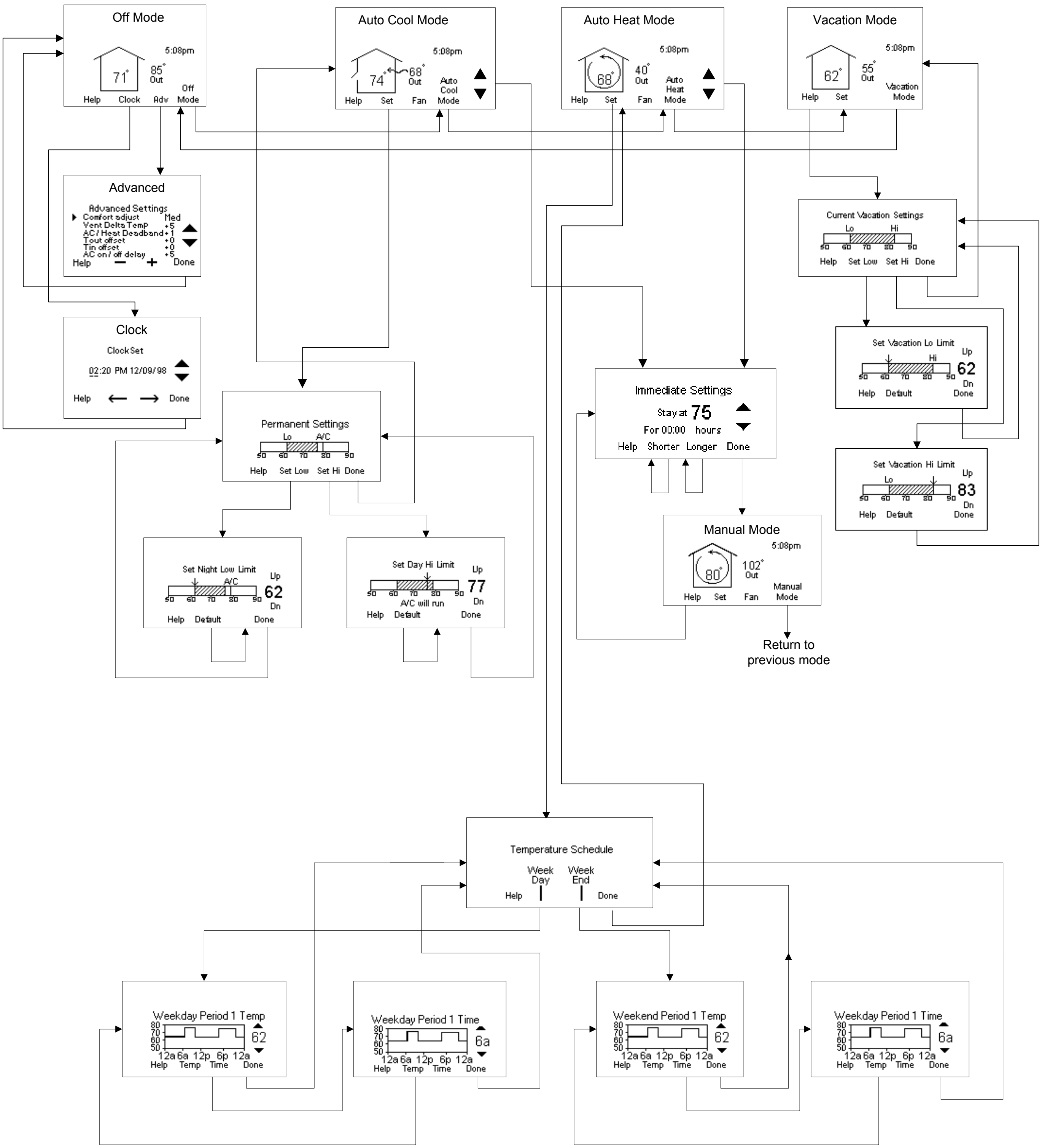
[3] This rate is an hourly average in CFM. The total volume of fresh air delivered each hour is the ventilation rate multiplied by 60.

ventilation function is disabled. If the indoor temperature rises to the vent target temperature and the indoor temperature is above the outdoor temperature (by the set differential), the fan and damper operate as described in Section 7. The vent target temperature is calculated using a comfort preference setting of +5 (see Section 7.2) to minimize the possiblity that the system will operate ventilation cooling and heating in the same day.

Attachment 1: NightBreeze Wiring Diagram – Rev B PCB



Attachment 2: Wall Display Unit Menu Tree



Attachment 3: Advanced Settings Menu

ADVANCED CONTROL SETTINGS		
Menu Item	**Description**	**Setting Range**
Comfort Adjust	Preferred comfort range.	-5 to +5
Vent Delta Temp	Indoor-outdoor temperature difference at which ventilation cooling will be initiated, °F.	0 to 9
Tout Offset	Outdoor temperature sensor calibration, °F.	-9 to +9
Tin Offset	Indoor temperature sensor calibration, °F.	-9 to +9
AC Mode	Air conditioner operating mode	*Standard* or *None*
AC on Delay	Time delay between condensing unit cycles, minutes.	0 to 5
Man Fan Time	Length of time fan will run when the *Fan* button is pressed, hours.	0 to 4
AC Fan CFM	Airflow for air conditioner operation, CFM	100 to 2100
Ventilation Rate	Average hourly airflow rate for heating mode fresh air ventilation, CFM.	0 to 95
Vent Fan CFM	Maximum airflow for ventilation cooling, CFM	100 to 2100
Heat Fan CFM	Maximum fan speed for heating operation, CFM.	100 to 2100
Man Fan CFM	Maximum fan speed for manual fan operation	100 to 2100

RCS

NightBreeze Control Unit PCB Assembly

Product Specification

PN: 005-00060

DCN: 116-00060

Attachment 4: PC Board Specification

Revision	Date	Engineer	Description	Approval
01	12/00	Kuhlmann	Initial Draft	
02	2/16/01	Kuhlmann	Hardware spec revision	
03	4/23/01	Kuhlmann	Feature spec revision	
04	6/19/01	Kuhlmann	Hardware spec revision	
05	7/2/01	Kuhlmann	Hardware spec revision	
06	11/21/01	Kuhlmann	Hardware spec revision: J1 connector	
07	11/28/01	Kuhlmann	Wiring Diagram revision 7: J7 connector	
08	04/01/02	Kuhlmann	Wiring Diagram revision 7B	
09	4/23/02	Kuhlmann	General Edits, Test Specs, PCB Drawings	

SECTION 1. PRODUCT DEFINITION

1.1 Introduction

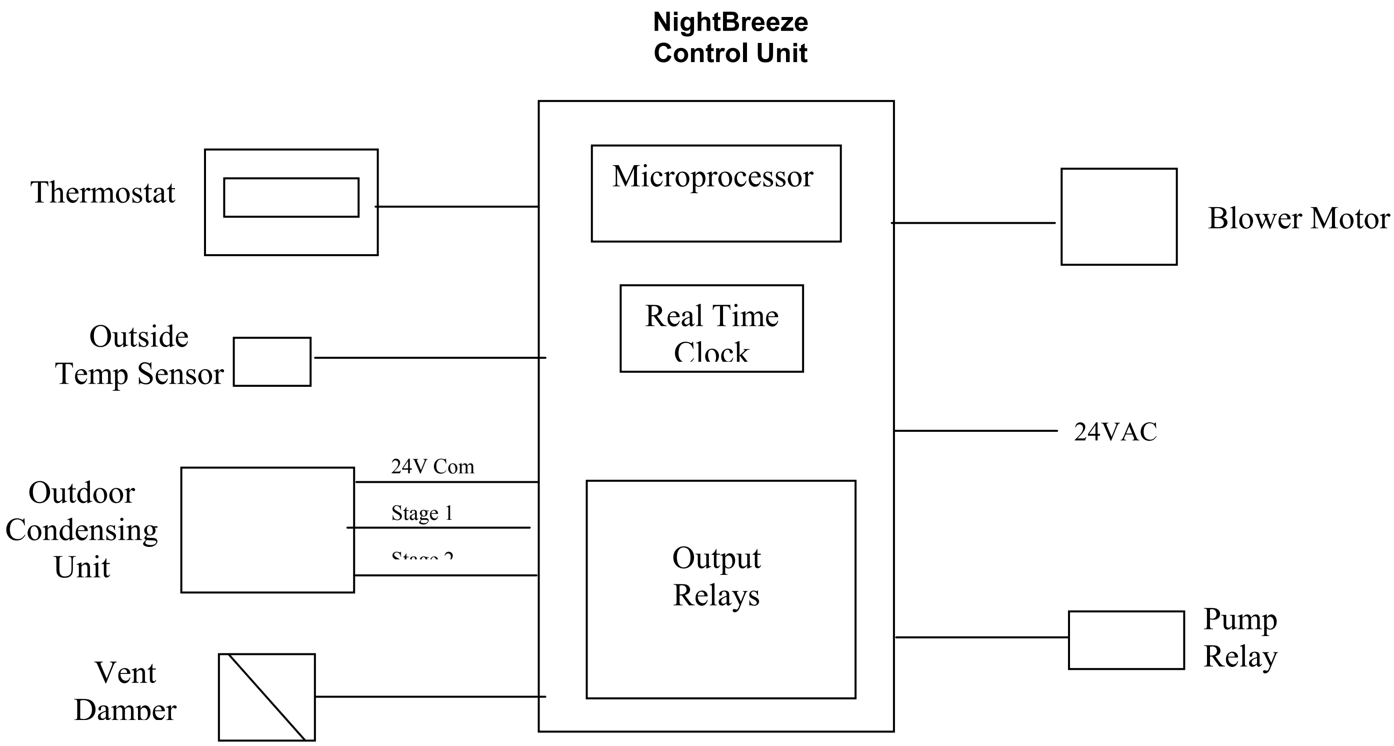
The NightBreeze control unit PCB assembly is the microprocessor based controller for the NightBreeze system. The system consists of a thermostat, outside air temperature sensor, vent damper, optional compressors, blower assembly with a variable speed motor, and a pump.

The control unit communicates with the thermostat and outside sensor to determine the current temperatures and various modes of operation of the NightBreeze. The control unit provides outputs to control the vent damper, blower motor speed, compressors and pump to achieve various modes of operation, including venting, heating and cooling. Special firmware in the thermostat and control unit work to provide integrated, intelligent venting to pre-cool the building to minimize compressor cooling and fan energy use. In addition, the unit provides fresh air ventilation for improved indoor air quality.

The control unit PCB assembly is mounted in the NightBreeze air handler enclosure.

Attachment 4: PC Board Specification

NightBreeze Control Unit Block Diagram



SECTION 2. HARDWARE SPECIFICATION

2.1 Inputs And Outputs

The NightBreeze Control Unit PCB assembly has inputs and outputs to control the NightBreeze system. These are described in detail as follows.

2.1.1 Thermostat Connection.

The thermostat is a custom TR36 Wall Display Unit (WDU). The WDU consist of a digital LCD display, control push buttons, and a digital temperature sensor. This device connects to the control unit by a four wire, power/data connection. The communication between the WDU and control unit uses a clock and data transmission protocol as specified by the RCSLink1 protocol document version 1.5. 12VDC Power for the thermostat is provided by the control unit.

2.1.2 Outside Temperature Sensor Connection.

The outside temperature sensor connection is a four wire, power/data connection. The communication between the WDU and control unit uses a clock and data transmission protocol as specified by the RCSLink1 protocol document version 1.5. 12VDC Power for the sensor is provided by the control unit.

2.1.3 Outdoor Condensing Unit Connection.

The Control unit provides for control of 1 stage and 2 stage compressor condensing units (2nd stage currently not implemented in firmware). Connections are 24VAC common, Stage 1 compressor and Stage 2 compressor. The relay contacts are isolated to allow for internal transformer condensing units. Optionally, a quick connect terminal is provided for sourcing the 24VAC to allow for condensing units without transformers.

2.1.4 Vent Damper Connection.

The vent damper motor is a three wire, power open, power close control. Outputs are 24VAC common, 24VAC relay controlled Open signal, and a 24VAC relay controlled Close signal. Power remains on either the Open or Close output continuously. The damper motor contains power limiting circuitry to allow for a continuous power signal.

2.1.5 Aux 24VAC Fused Connection.

The Control Unit provides an auxiliary 24VAC fused output for use with condensing units with out internal transformers.

2.1.6 Blower Motor Connection.

The Control Unit drives the GE ECM variable speed blower motor. Outputs to drive this motor are DC ground (C2), variable Pulse Width Modulating (PWM) signal (BK), and a relay switched 12VDC signal for the fan call (G).

2.1.7 Pump Relay Connection.

The pump output is a relay controlled 24VAC output that drives the Pump relay to switch 120v main power to pump motor.

2.1.8 Power Input.

The Control Unit has a 24VAC power input. The input is fused with an ATO style fuse. This fuse protects the input power to the Control Unit and the 24VAC power outputs. Fuse Rating: 2 Amp.

2.1.9 Input/Output Connection Table

Terminal Name	Connector	Electrical Connection	Reference
Field Wiring Terminal	12 Pos MTA 156 Header		J1
DC Ground	Pos 1	Gnd	J1-1
12VDC	Pos 2	+12VDC	J1-2
Thermostat Ck	Pos 3	Tstat Clock	J1-3
Thermostat Data	Pos 4	Tstat Data	J1-4
OT Sensor Ck	Pos 5	OS Clock	J1-5
OT Sensor Data	Pos 6	OS Data	J1-6
Outdoor Condensor 24VAC Com	Pos 7	24VAC Compressor	J1-7
Outdoor Compressor Stage 1	Pos 8	24VAC Relay K1 NO	J1-8
Outdoor Compressor Stage 2	Pos 9	24VAC Relay K2 NO	J1-9
Vent Damper Open	Pos 10	24VAC Relay K3 NO	J1-10
Vent Damper Close	Pos 11	24VAC Relay K3 NC	J1-11
Vent Damper 24VAC Com	Pos 12	24VAC Com	J1-12
24R Fused	Terminal: Quick Connect .250	24VAC Return Fused	J2
ECM Motor	3 Pos MTA 156 Header		J3
C2	Pos 1	DC Gnd	J3-1
BK	Pos 2	PWM	J3-2
G	Pos 3	12VDC Relay K4	J3-3
Power C	Terminal: Quick Connect .250	24VAC Com	J4
Power R	Terminal: Quick Connect .250	24VAC Ret	J5
Pump W	Terminal: Quick Connect .250	24VAC Relay K5	J6
Pump C	Terminal: Quick Connect .250	24VAC Com	J7

2.1.10 Output Relays

The output relays will be 12VDC sensitive coil relays with SPDT contacts rated for 1Amp at 30VAC.

2.1.11 Relay Contact Protection

The relay contacts will be protected by 56V 600W MOV diodes.

2.1.12 Thermostat and Outside Sensor Data Line Protection

The Thermostat and Outside Sensor connections will be protected by 6.0V Transient Voltage Protection Diodes.

2.1.13 Thermostat and Outside Sensor Power Line Protection

The Control Unit will source 12VDC to power the Thermostat and the remote temperature sensor. 300 Ma of power will be available for these devices. The 12VDC power line will be protected by 20V transient voltage (TVS) protection diodes.

2.2 Real Time Clock

2.2.1 The Control Unit will have a real time clock IC to allow accurate control of time of day schedule operation.

2.2.2 The RTC device will be the Dallas 1302.

2.2.3 Backup: A supercap will be used to provide for power fail backup power to keep the RTC time base running for at least 24 hours.

2.2.4 The real time clock will be set via the Thermostat.

2.3 Microprocessor Specification

The Control Unit will use a flash based microprocessor with In-Circuit programming capability.

Feature	**Specification**			
Word size	16 Bit			
I/O Pins	22			
ISP	Yes			
Memory Type	Flash			
Memory Size	8 K words			
Ram	368 x 8 bytes			
EEPROM	256 x 8 bytes			
Serial Uart	1			
Oscillator	Xtal 1Mhz			
Packaging	SOIC28			

2.3.2 Target Microprocessor is the Microchip PIC16C876.

2.4 Power Requirements

2.4.1 Input Power Requirements:

20-30VAC 40VA for Thermostat, Sensor, Damper, Motor control, and pump relay.

2.4.2 Internal Power Supply:

The control unit PCB will have an on-board high efficiency switching regulator that converts the input 24VAC to 12VDC at 500mA. A secondary linear regulator will provide 12VDC to 5VDC at 100mA conversion for the logic power. The primary 24VAC to the switching regulator input is fuse protected by a resettable 200mA fuse. In addition, the 12VDC output to off board devices is fuse protected by a 200mA resettable fuse. The resettable fuses will return to normal operation within 5 minutes of removal of circuit overcurrent cause.

2.5 Fuses

24VAC Input: ATO style replaceable 2A fuse

Internal power: resettable 200mA fuse

External 12VDC output: resettable 200mA fuse

2.4 PCB Specification

2.4.1 PCB Size: 3.5 x 4 inch

2.4.2 PCB Material: FR4; 94V-0 UL rated

2.4.3 PCB Mounting:

The Control Unit will mount to the NightBreeze Air Handler frame with 4 insulated plastic standoffs.

2.5 Wiring Diagram

Refer to RCS NightBreeze wiring diagram version 7B, dated 4/01/02.

2.6 Test Specifications

2.6.1 The NightBreeze control PCB assembly shall be tested to following test specifications:

1. Immunity Tests per EN55014-2 (1997)
    a. IEC 61000-4-2 (1995)Electrostatic Discharge (+/-8kV Air/+/-4kV Discharge)
    b. IEC 61000-4-3 (1995)RF Radiated Fields (3mV, 80-1000MHz, 80%AM@1KHz)
    c. IEC 61000-4-4 (1995)Electrical Fast Transients/Burst (+/-1kV AC line;+/-0.5kV I/O Lines > 3m)
2. Emissions Test
    a. FCC 15B, Class "B" Radiated (RF) Emissions Test (30-1000MHz)

Attachment 4: PC Board Specification

2.6.2 Test Certification

The control PCB assembly, installed in the NightBreeze air handler unit, was tested to the Test Specifications 2.6.1 and certified to comply.

Testing Agency: Nemko USA, Inc

11696 Sorrento Valley Rd. Suite F

San Diego, CA 92121-1024

Test Report: Summary Report 22-055, 4/16/02.

SECTION 3. FIRMWARE SPECIFICATION

Overview

The NightBreeze Control Unit PCB assembly firmware is provided by Davis Energy Group. Refer to the DEG NB firmware specifications for details.

3.1 Thermostat Communications

The control unit communicates to the thermostat using a two wire clock and data communications protocol. The communications protocol is defined by RCS document: RCSLink Protocol, Revision 1.5.

3.2 Outside temperature Sensor

The control unit communicates to an outside temperature sensor using the same two wire clock and data communications protocol as the thermostat.

3.3 Condensing Unit

The control unit controls a Stage 1 compressor output and a Stage 2 compressor output (currently not implemented in firmware). The Control unit controls these outputs to provide cooling according to the temperature, setpoint and mode information provided by the thermostat. Refer to the DEG NB firmware specification document.

3.4 Vent Damper

The control unit controls the position of the Vent Damper. The damper is 100% open during venting operation and is 100% closed when not venting. Refer to the DEG NB firmware specification document.

3.5 ECM Motor Control

The control unit supplies a PWM signal to the ECM motor to control blower speed. Motor speed can be set from 0 to 100% with the PWM signal. Refer to the DEG NB firmware specification document.

3.6 Pump Relay Control

The control unit controls the pump relay to provide heating control according to current temperature, setpoints and mode information from the Thermostat. Refer to the DEG NB firmware specification document.

3.7 Vent Operation

The control unit has several automatic ventilation features. The vent damper is controlled according to the current indoor temperature, outside temperature, setpoints and mode information. Refer to the DEG NB firmware specification document.

3.8 Scheduling

The control unit can store and execute a schedule for time of date changes to setpoints. Refer to the DEG NB firmware specification for details on the scheduling capabilities.

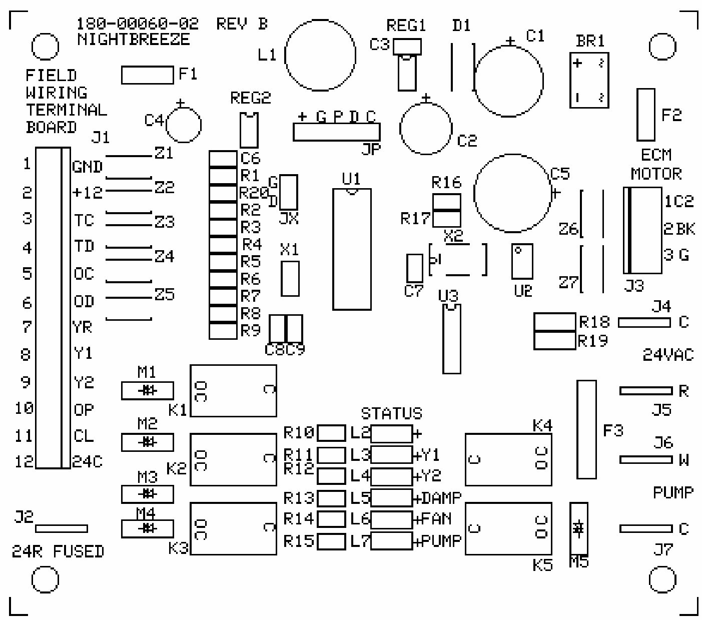
Attachment 4: PC Board Specification

3.9 System Variables

Refer to the DEG NB firmware specification for a list of the systems variables.

Attachment 1

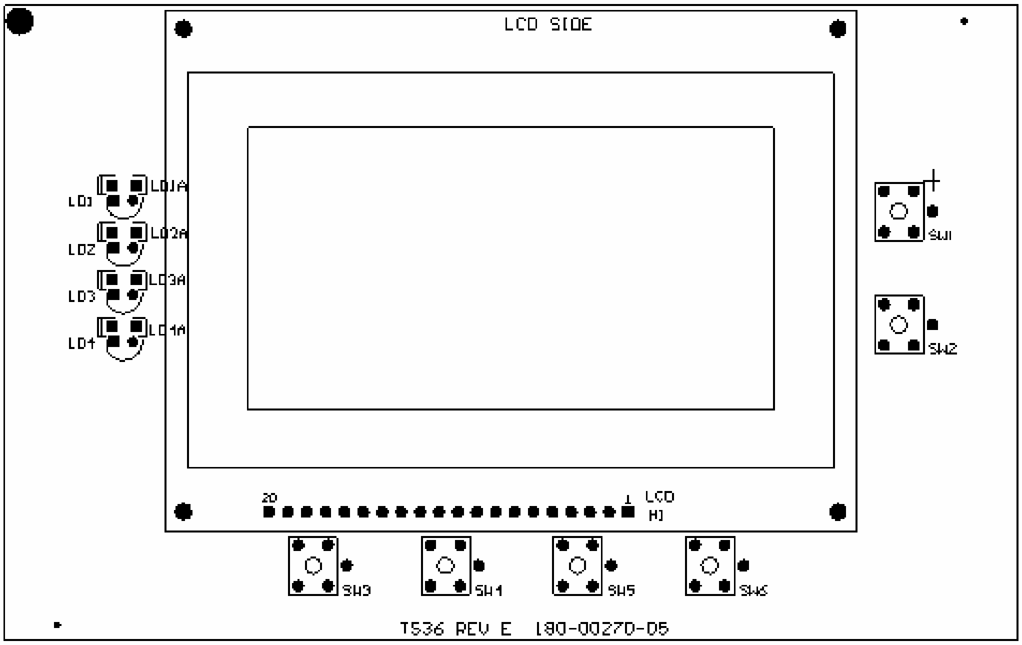
NB Control Unit
PCB Assembly

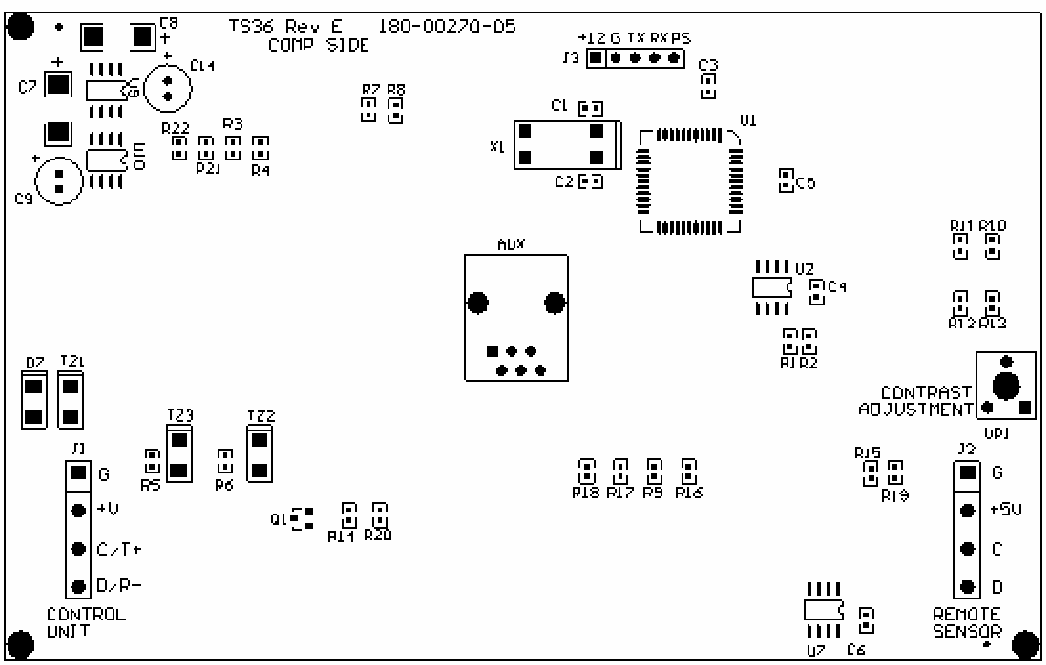


Attachment 4: PC Board Specification

Attachment 2

TS36 Wall Display Unit
PCB Assembly

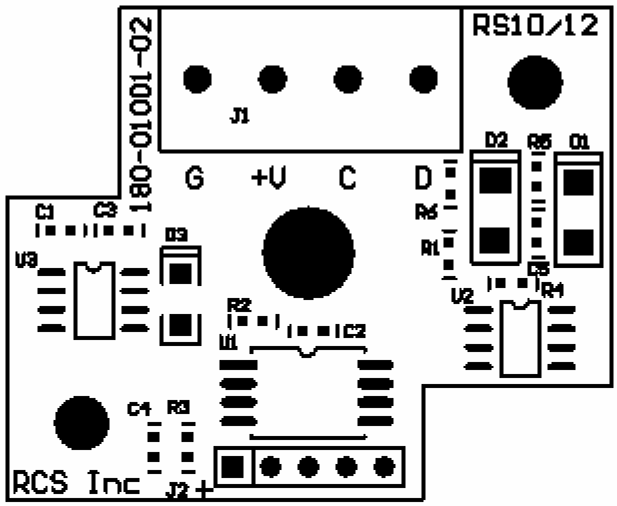




Attachment 4: PC Board Specification

Attachment 3

RS10 Remote Temperature Sensor
PCB Assembly



Alternatives To Compressor
Cooling Project

Advanced Control Functional Enhancements Report

PIER Contract #500-98-024

Date Completed: April 30, 2002

Presented to: Phillip Spartz
California Energy Commission

Prepared by: David Springer
Leo Rainer
Bill Dakin

1 Background and Objectives

1.1 Background

This report presents the results of work completed under Task 2.2.1 of the Public Interest Energy Research multi-phase project titled Alternatives to Compressor Cooling (ACC). Controls were developed under this and previous phases of the ACC project for the purpose of operating night ventilation cooling, heating, and air conditioning functions in an integrated comfort system which has been given the name "NightBreeze".

During the development of the control many "best guesses" of control parameters had to be made in order to create working control logic that could be tested. Field testing to date has demonstrated that control functions appear acceptable, but testing the impact of a variety of control options in the field would require years of data collection. The purpose of this task was to employ computer simulations to identify optimal values for these parameters.

When originally completed, this study included an evaluation of the effectiveness of using an air conditioner to pre-cool building mass in order to shift cooling loads to off-peak periods. The initial analysis did not consider time-of-use rate economics. A subsequent independent study of pre-cooling was completed in 2003 and did employ a time-of-use rate analysis. This study produced more favorable findings, and although not completed as an ACC project task, it is appropriate to include a report documenting the second evaluation an appendix to this report.

1.2 Objectives

The end objective of this work is to complete the draft Functional Control Specification developed in the previous project phase. The specification consists of two parts, hardware and firmware. The focus of work under this task is on firmware.

Task objectives from the Statement of Work included evaluation of alternative control capabilities for:

- Ventilation cooling
- Winter (heating mode) fresh air ventilation
- Off-peak pre-cooling using a condensing unit

Several coefficients are used in firmware calculations that determine fan speed relative to cooling demand. Parametric analysis was needed to determine whether the value of these coefficients could be improved in order to reduce combined ventilation and air conditioning system energy.

Winter fresh air ventilation obviously results in increased energy fan use (compared to no ventilation). The objective of the evaluation of fresh air ventilation was to determine the magnitude of this penalty, not to inform changes to control strategies[1].

[1] Energy consumption resulting from winter fresh air ventilation is also being determined from monitoring studies.

The is a potential for shifting cooling load to off-peak periods by operating air conditioning during late night and morning hours in order to pre-cool building mass. The need for pre-cooling is particularly strong on those nights when outdoor air temperatures are not sufficiently low to enable ventilation cooling to be effective. The objective of pre-cooling analysis was to identify potential peak load shifting advantages.

1.3 Overview of Ventilation Cooling Control Functions

A brief description of the ventilation control approach will provide a context for the discussion of the analysis completed for this task.

To maximize comfort and to conserve fan energy use, controls vary the amount of nighttime ventilation cooling as a function of how much cooling the house is likely to need on the following day. This *ventilation cooling demand* is determined from predictions of the next day's temperatures, which are calculated from a measured temperature history. Fan operation is initiated as soon as the outdoor temperature falls below the indoor temperature by some differential (which can be user-selected). Fan operation is terminated when the differential no longer exists, or when the indoor air temperature falls below a specified low limit.

The extent of ventilation cooling provided is regulated two ways: by varying the effective low limit temperature, and by varying the airflow rate. Both are recalculated by the control each day (at midnight), and both are affected by user control settings (low limit, air conditioner setpoint, comfort preference, and maximum CFM)[2]. On mild days the effective, or "target", low limit temperature is raised above the user's low limit setting, and the fan operates at lower speeds. On the hottest days the vent target temperature approaches the user setting and the fan runs at its maximum speed[3]. Predictions of next-day's temperatures that are determined from an outdoor/indoor temperature history are used to establish both the effective low limit temperature and fan speed.

2 Methods

2.1 DOE-2 Model

The simulation tool used for this analysis was developed by Joe Huang under a previous project phase, and incorporates a special control function developed in the current project phase. The special function applies identical control algorithms as are used by the NightBreeze control to operate the fan for ventilation cooling, air conditioning, heating, and fresh air ventilation. The special function also includes fan power curves for calculating fan energy use from airflow rate[4].

---

[2] The low limit setting and air conditioner setpoint are user settings; comfort preference and maximum CFM are set in "Advanced Settings" by the installer. Comfort preference settings were not analyzed.
[3] Maximum ventilation CFM can be set in the "Advanced Settings" menu of the thermostat.
[4] The fan power curve was determined from PG&E tests conducted on the prototype air handler developed under Task 2.1.

2.2 House Model

The *Inland Valley House* designed by Loisos/Ubbelohde under Task 2.3 of this project was used in simulations to test control functions. The 1860 ft^2 one story house incorporates several features to improve summer performance, including 50% of slab floor exposed (tiled) and 5/8" drywall for added thermal mass, slab perimeter insulation, radiant barrier, high performance windows, and exterior window shading. Since the house performs similarly in all orientations, all analyses were completed using the worst-performing orientation (front facing west)[5].

To determine the extent to which house design affects ventilation cooling performance, a version of the house that only meets prescriptive Title 24 requirements (including AB970 improvements) was also subjected to limited evaluation. The primary difference between the original *Inland Valley House* design and the prescriptive house is overhang length (the *Inland House* design included 36" overhangs whereas the Title 24 design used 12" overhangs), and thermal mass (the *Inland House* includes 50% exposed floor mass and 5/8" instead of ½" drywall). Simulations assumed that the mechanical system was the only source of ventilation (no window operation), since DOE-2 cannot model fan and stack/wind-driven ventilation concurrently.

2.3 Climate Zones

Analysis was completed in each of four climate zones to identify weather dependency of results. These climate zones included Zone 4 (Sunnyvale), Zone 10 (Riverside), Zone 12 (Sacramento), and Zone 13 (Fresno). Zone 4 offers some potential for the elimination of compressor cooling, consistent with the ideal project goal.

2.4 Parametric Analysis: Temperature Settings

All parametric analysis used an 80°F air conditioner setpoint. This setpoint is justified on the basis that the added thermal mass and high performance windows will provide lower mean radiant temperatures, and thus better comfort at higher indoor air temperatures, and that ceiling fans are used to enhance comfort. The assumption probably yields conservative estimates of energy savings because of lower cooling loads.

2.5 Parametric Analysis: Ventilation Cooling Optimization

The following parameters were evaluated to optimize both fixed and user variable control inputs:

- **Maximum airflow rate.** In addition to establishing the maximum airflow rate delivered by the system, this parameter establishes the slope of the curve that relates ventilation cooling demand to airflow rate. At 100% demand the airflow is equal to the maximum CFM setting entered into the control, and at 50% demand the airflow is 50% of the maximum. This is a critical parameter in that it affects the tradeoff between fan energy use and air conditioner energy use. Since fan energy use varies with the cube of the airflow, energy use can be nearly 50% of air conditioner energy use at higher CFM's. The optimal maximum airflow is likely to vary with both house design/size and climate. The objective here is to develop guidelines for selecting the

[5] The house was designed to perform similarly in all orientations.

correct maximum airflow value in the control settings. Expressed as a function of peak cooling load (e.g. Max CFM per ton), this value can be used to establish the preferred airflow rate for a particular house.

- **Cooling demand parameters.** Control algorithms include an equation to calculate the ventilation cooling airflow rate that involves three parameters. The default values originally used for these parameters were "educated guesses" based on observations of system operation. To find values that would result in the least annual cooling energy use (fan and condenser), the value of these parameters were varied.

2.6 Parametric Analysis: Mechanical Pre-cooling

The added thermal mass included in the *inland valley house* affords the opportunity to shift peak load by operating the air conditioner during early morning hours to augment ventilation cooling on those days when the nighttime temperature does not drop sufficiently to significantly reduce daytime air conditioning load. This approach has the added benefit of higher air conditioner EER's due to lower outdoor temperatures, but the cooling reserve that is stored in the building mass is also depleted over the course of the day, so that more energy is needed to accomplish an equivalent amount of cooling. The goal of this analysis task was to determine whether the reduction in peak load justifies the added energy expended by the air conditioner. The model scheduled the air conditioner to operate between the hours of 5 AM and 8 AM using an indoor setpoint of 70°F, and annual energy use was compared to energy use for the non-precooling case.

In order to assign time-of-use value to the cooling energy determined from the simulations, the same TDV multipliers used in the development of updates to the 2005 standards were applied to convert "site" energy to TDV (source) energy. Hourly energy use values for the base case and the pre-cooling cooling cases were multiplied by the corresponding hourly TDV multipliers, which also vary by climate zone.

2.7 Winter Fresh Air Ventilation

Simulations were completed to estimate the energy penalty for providing winter fresh air ventilation using the NightBreeze system. Since the house is assumed to be built to "tight" standards, winter ventilation in the base case analysis does not meet ASHRAE 62-89 standards of 15 CFM per person. DOE-2 simulations applied a 60 CFM average ventilation rate and used the same equation for calculating fan energy use as was used for the cooling analysis.

3 Results

3.1 Optimal Maximum Ventilation Cooling Airflow Rate

Figures 1 through 4 graph the results of the simulations completed to determine the optimal value for maximum ventilation cooling airflow rate when minimizing annual energy use is the objective[6]. Figure 1 indicates that an airflow rate of 800 CFM results in the least energy use for Climate Zone 4. However, a ventilation rate of 1147 CFM comes

[6] If minimizing peak load is the objective a different optimum might be found.

very close to eliminating all air conditioner energy use and is likely to result in the most cost-effective solution because the cost of installing an air conditioner is avoided.

In Climate Zone 10 (Figure 2) high airflows result in reduced air conditioner use, but a ventilation rate of 1147 CFM yields the lowest total energy use. Similar trends are seen in zones 12 and 13, though total energy use varies.

Figures 5 through 8 graph the maximum ventilation cooling airflow rate parameters for the house that only meets prescriptive Title 24 requirements. The window properties and glazing areas are based on the Title 24 prescriptive package requirements and vary with the climate zone in which the house was run. In Climate Zone 4 (Figure 5), the airflow rate of 1147 CFM yields the lowest energy use. The optimal value is higher than for the Inland Valley house, probably because the cooling energy use is significantly higher for the Title 24 house. The optimal maximum ventilation cooling airflow rates for the remaining climate zones (Figures 6 through 8) are the same (1147 CFM), even though the cooling loads are higher for the Title 24 compliance house.

Figure 1: Energy Use vs. Max Vent CFM
Inland Valley House, Climate Zone 4

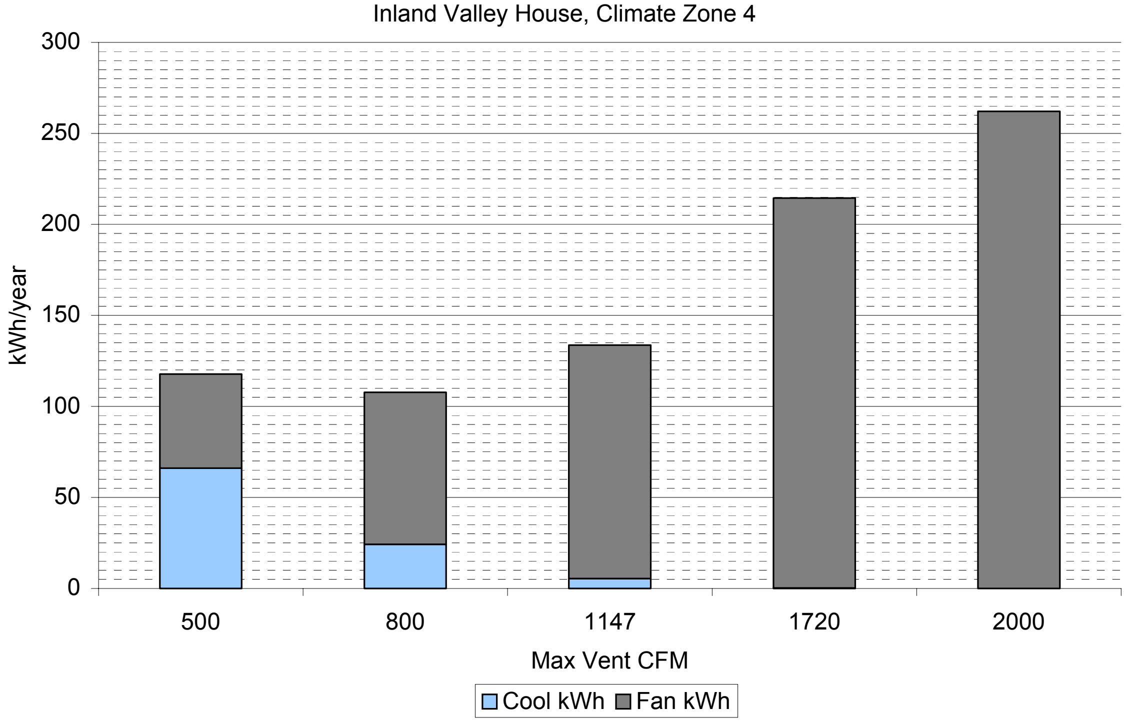


Figure 2: Energy Use vs. Max Vent CFM
Inland Valley House, Climate Zone 10

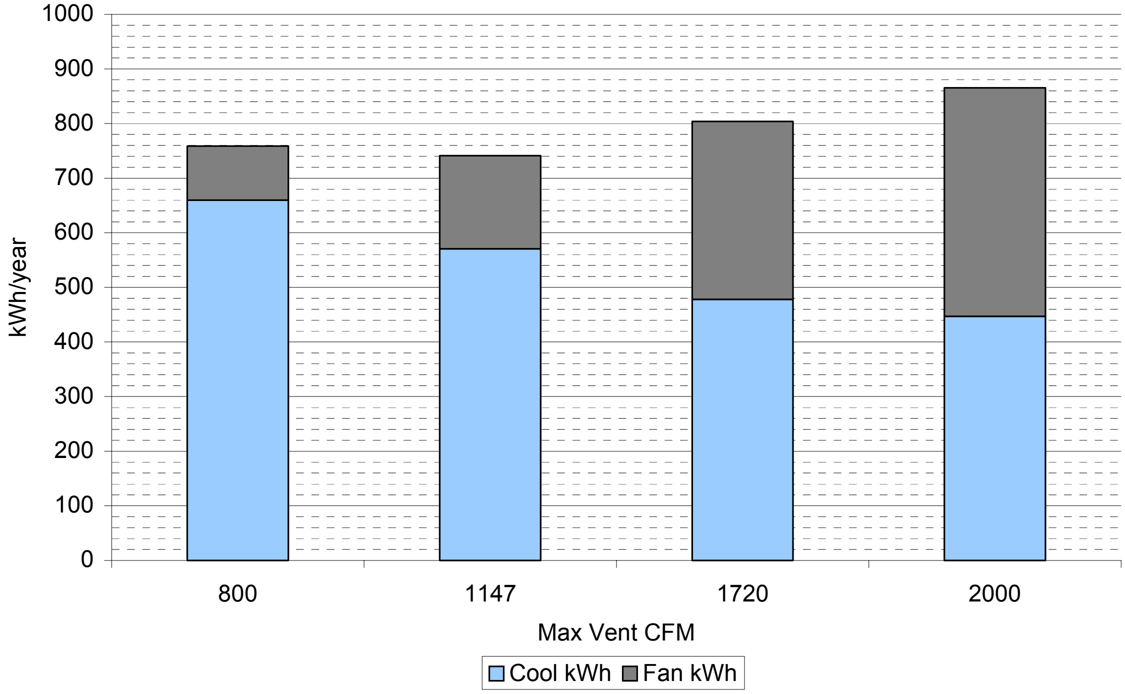
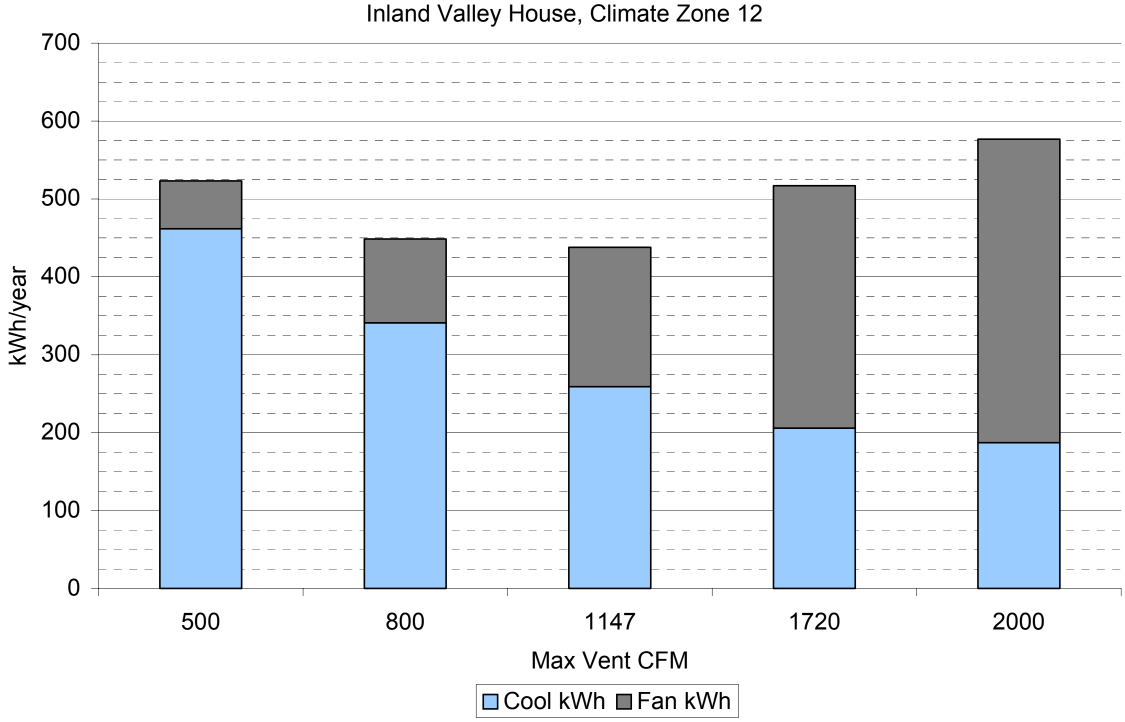


Figure 3: Energy Use vs. Max Vent CFM
Inland Valley House, Climate Zone 12



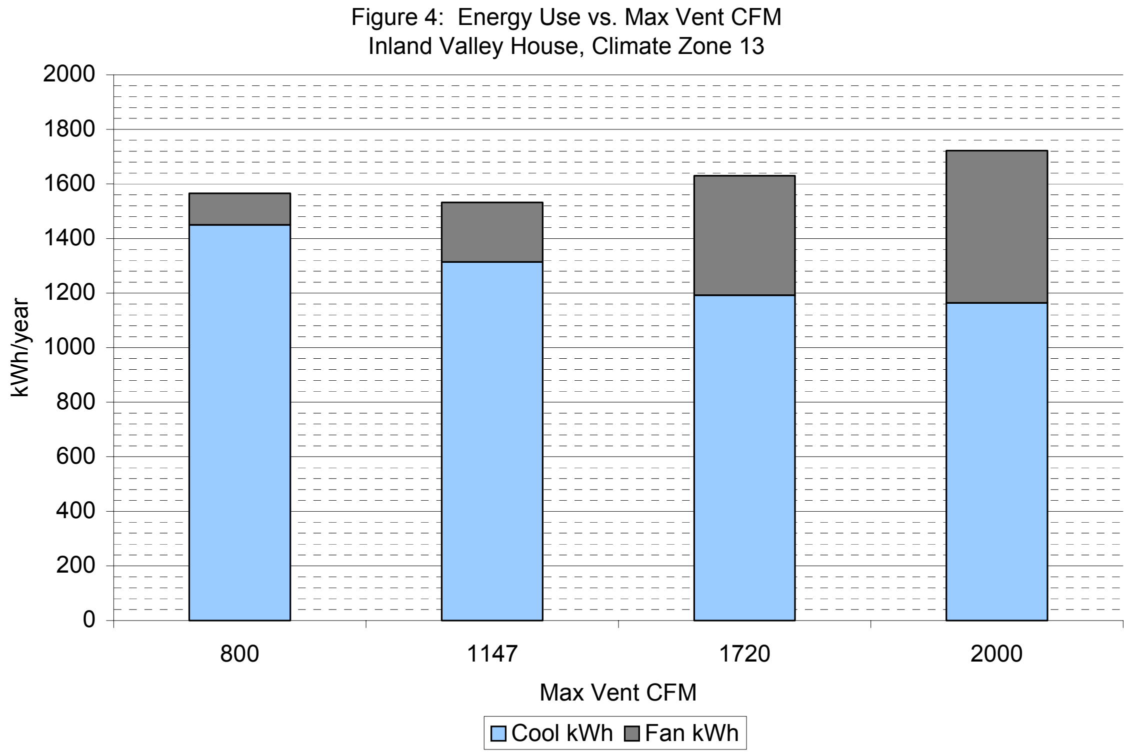


Figure 4: Energy Use vs. Max Vent CFM
Inland Valley House, Climate Zone 13
kWh/year
0
200
400
600
800
1000
1200
1400
1600
1800
2000
800
1147
1720
2000
Max Vent CFM
Cool kWh
Fan kWh

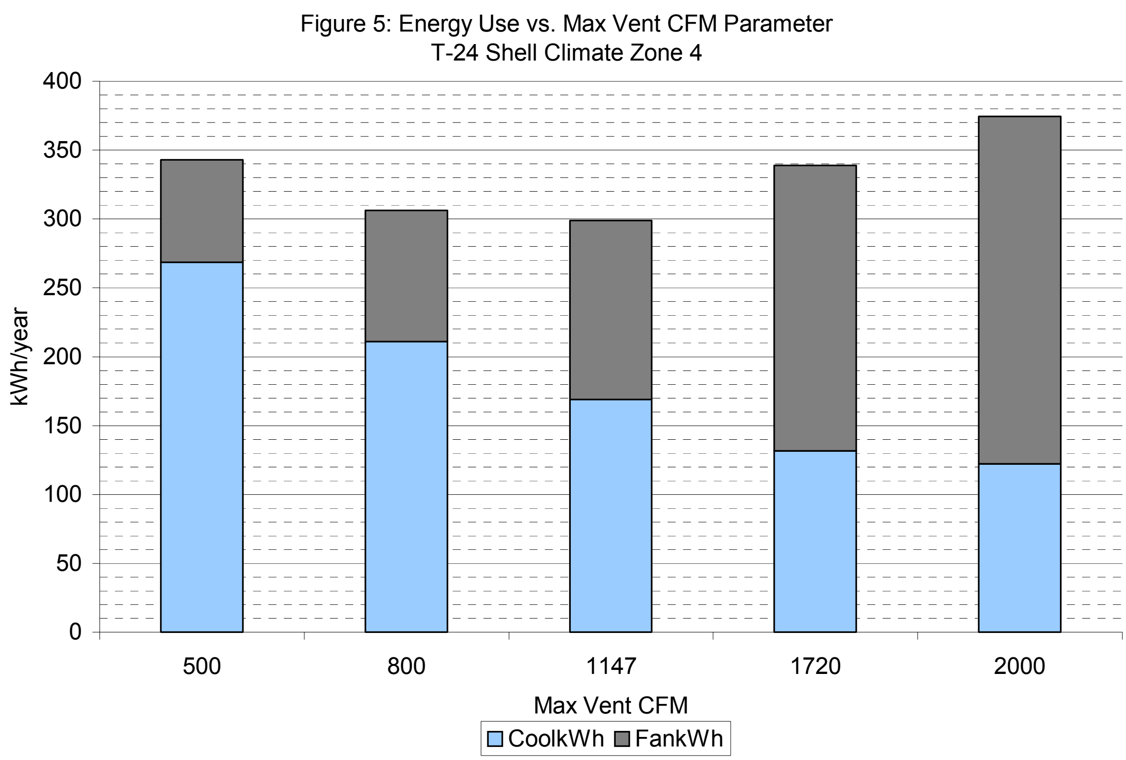


Figure 5: Energy Use vs. Max Vent CFM Parameter
T-24 Shell Climate Zone 4
kWh/year
0
50
100
150
200
250
300
350
400
500
800
1147
1720
2000
Max Vent CFM
CoolkWh
FankWh

Figure 6: Energy Use vs. Max Vent CFM Parameter
T-24 Shell Climate Zone 10

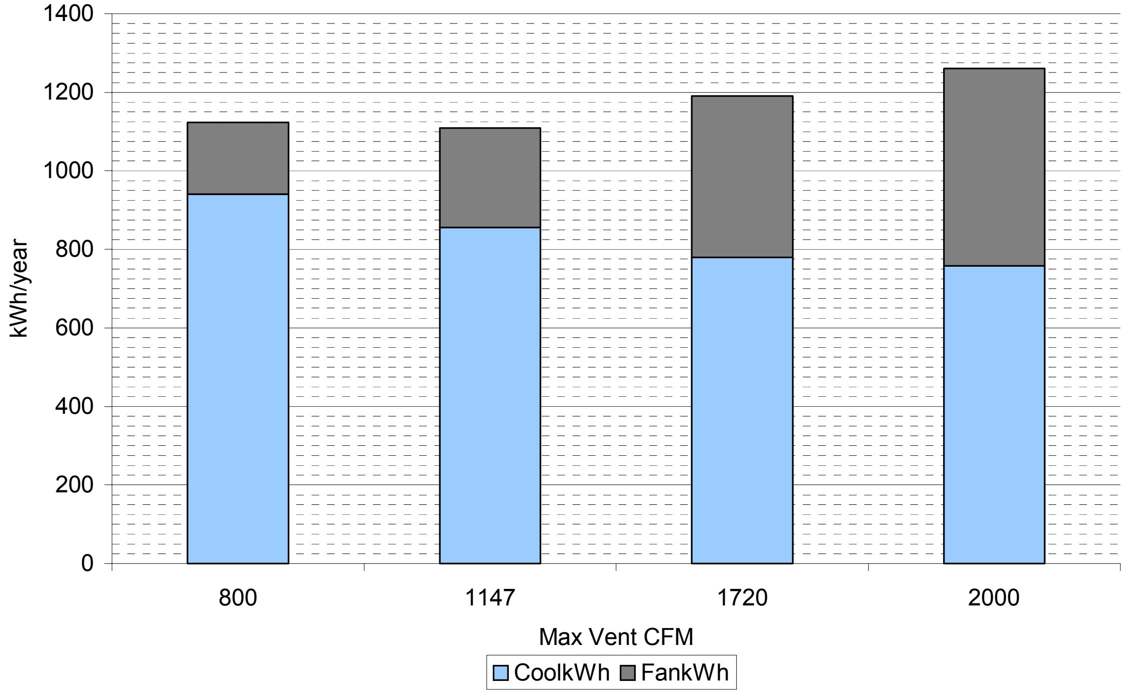
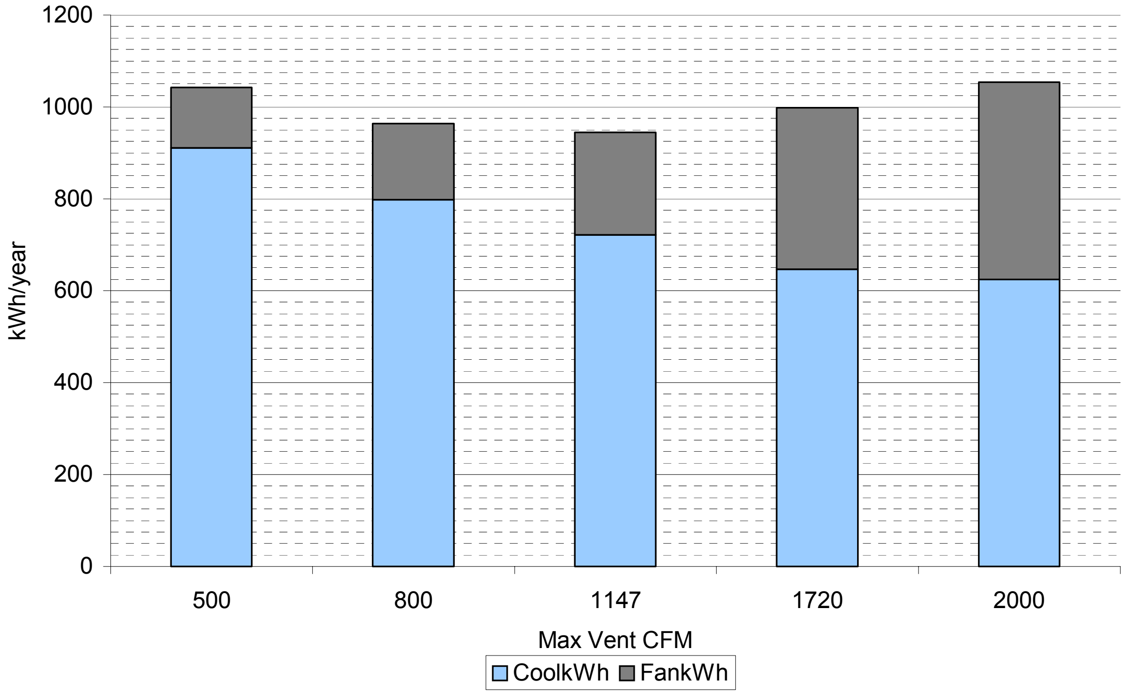
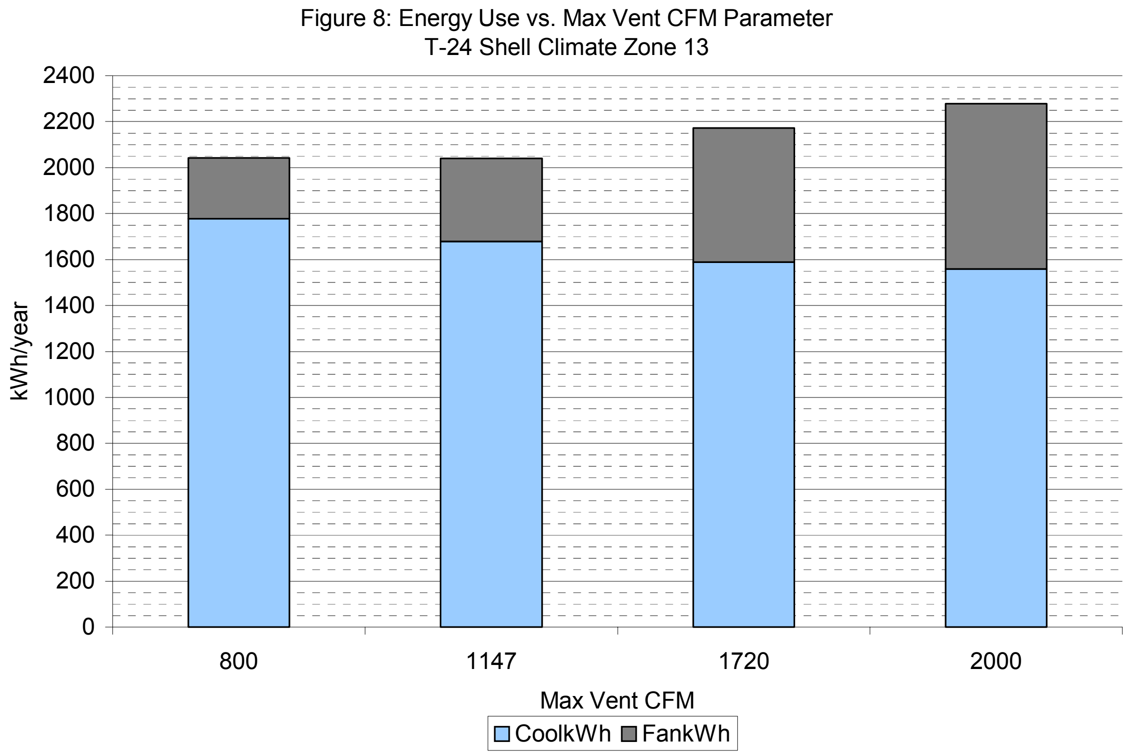


Figure 7: Energy Use vs. Max Vent CFM Parameter
T24 Shell Climate Zone 12





3.2 Optimal Cooling Demand Parameters

Figures 9 througy 12 show the results of the simulations that were run to compare the ventilation rate equation coefficients, the 'delta-T' coefficient and outdoor temperature parameters. As shown by figures 9 & 10, varying the delta-T coefficient affects energy use by no more than 3%. In Climate Zone 4 there is a 3 kWh reduction when the delta-T coefficient is increased from 0.1 to 0.13. In Climate Zone 12 the same change results in a 4 kWh increase. Given these results the 0.1 default value appears to be optimal across the two climate zones.

Figures 11 and 12 show the results of the simulations in which the two outdoor temperature parameters were varied. In Climate Zone 4 using a lower value increased fan energy use more than it decreased compressor energy use, and using a higher value for had the opposite effect, but reduced total energy use by only 4 kWh. Figure 12 shows that the default values of 70/20 result in the least annual energy use.

Two conclusions can be drawn from these studies. First, annual energy savings are impacted very little by changes in the parameters evaluated. Second, the default parameters appear to be optimal, given that the same control strategy, with fixed parameters, will be applied to both coastal transition and inland valley climates.

Figure 9: Cooling Energy Use vs. Vent Delta-T Coefficient
Climate Zone 4

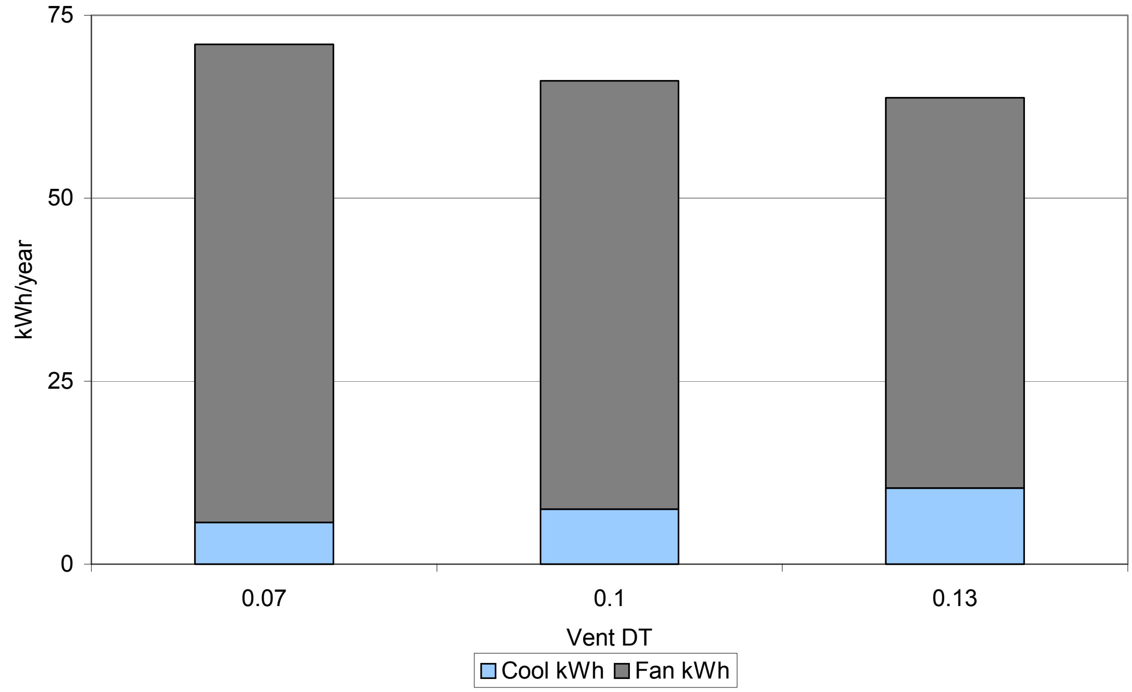


Figure 10: Cooling Energy Use vs. Vent Delta-T Coefficient
Climate Zone 12

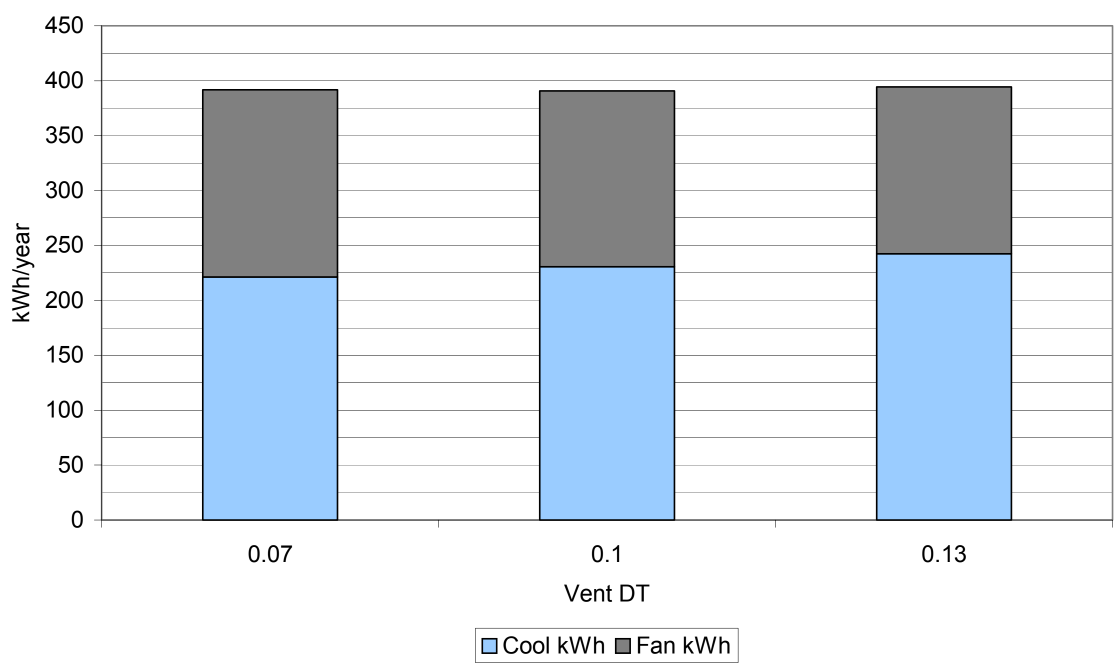


Figure 11: Cooling Energy Use vs. Outdoor Temperature Parameters
Climate Zone 4

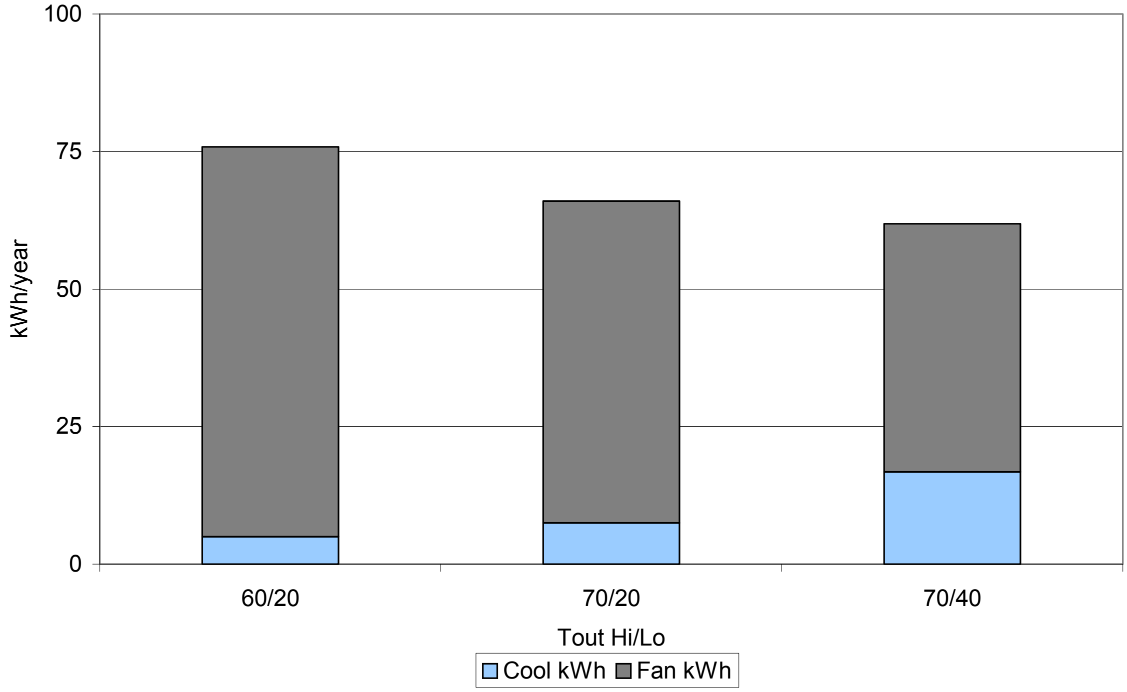
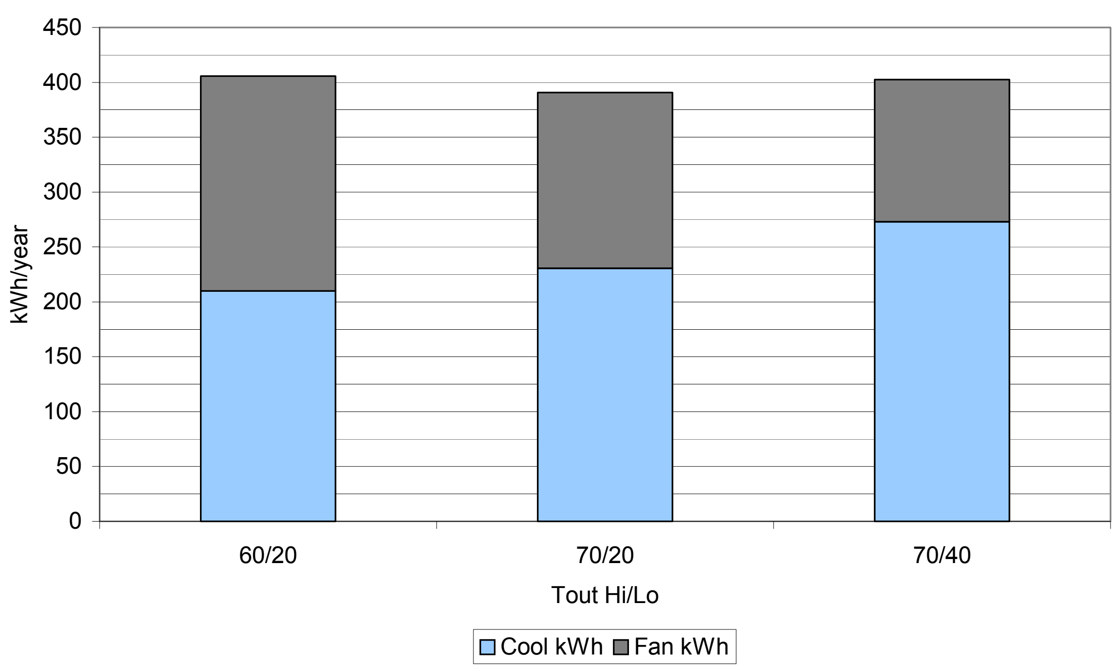


Figure 12: Cooling Energy Use vs. Outdoor Temperature Parameters
Climate Zone 12



3.3 Mechanical Pre-Cooling[7]

Tables 1 and 2 list the results of the analysis to assess the value of pre-cooling the house by operating the air conditioner during early morning hours. Results are expressed both in annual "site" kWh usage and in Time Dependent Valuation (TDV) energy. The latter values were determined by multiplying each hourly energy use value by the TDV conversion factor for that hour and climate zone.

Savings are negative from both a site energy and TDV perspective. This indicates that the cooling accomplished during morning hours at higher air conditioner EERs (due to lower outdoor temperature) does not adequately carry over to offset air conditioning load occurring later in the day. When TDV multipliers are applied the magnitude of the negative savings decreases, suggesting that load is being shifted off-peak. The very high TDV energy use in Climate Zone 4 is a result of relatively flat TDV multipliers; on-peak multipliers are not substantially higher than off-peak multipliers, so off-peak energy is not as highly valued as for the other locations. (Note that the units for Site and TDV savings are different.)

Table 2 compares site and TDV percentage energy savings, and shows that application of TDV multipliers significantly improves the energy savings picture, but does not go far enough to justify morning air conditioner operation. In Climate Zone 4 the air conditioner may have been operating unnecessarily, since pre-cooling to the 70°F setpoint was probably not required to keep afternoon temperatures below 80°; this explains the high negative TDV savings percentage in Table 2. It is possible that improved control strategies could improve savings slightly.

Table 1: Annual Energy Use and Savings from Pre-Cooling Analysis

	Vent Cooling		***AC Pre-Cooling***		***Savings***	
Location	***Site (kWh/yr)***	***TDV (kBtu/yr)***	***Site (kWh/yr)***	***TDV (kBtu/yr)***	***Site (kWh/yr)***	***TDV (kBtu/yr)***
CZ04	156	1659	262	2795	-106	-1136
CZ10	751	16602	977	16835	-226	-233
CZ12	470	8726	585	8930	-115	-204
CZ13	1555	27206	1788	27444	-233	-238

Table 2: Percentage Savings from Pre-Cooling Analysis

	% Savings	
Location	***Site***	***TDV***
CZ04	-67.9%	-68.5%
CZ10	-30.1%	-1.4%
CZ12	-24.5%	-2.3%
CZ13	-15.0%	-0.9%

[7] See Appendix for an alternate analysis of pre-cooling.

3.4 Winter Fresh Air Ventilation

Table 3 lists the results of simulations comparing no winter fresh air ventilation to simulations with winter ventilation meeting ASHRAE 62-1989 of 15 CFM per person (60 CFM total)[8]. As indicated, an additional 16 to 19 kWh for operating the fan, and an additional 34 to 61 therms of gas to offset the added heating load are needed. The annual cost penalty for meeting ASHRAE fresh air standards is approximately $25 to $40, depending on the climate zone, most of which is gas energy for heating.

The additional gas usage listed in Table 3 would be identical for any system that provides the same volume of fresh air ventilation (except for heat recovery ventilators). Operating at minimum speed the G.E. variable speed motor used in the NightBreeze air handler has a very low (less than 0.25) Watts per CFM. Combining this efficiency with the fact that ventilation can be provided during heating system operation without requiring additional fan energy, electrical energy use for this system should be much lower than for stand-alone ventilation systems.

Table 3: Energy Penalty Associated with Winter Fresh Air Ventilation

	Base Case		*60 CFM Winter Vent*		*Additional Energy Use*	
Location	***KWh***	***Therms***	***KWh***	***Therms***	***KWh***	***Therms***
CZ04	150	140	168	196	17	56
CZ10	180	59	194	93	14	34
CZ12	211	208	230	269	19	61
CZ13	241	146	257	196	16	50

4 Conclusions & Recommendations

Results of the analyses described in this report indicate that no further changes to existing control parameters are needed to optimize control operation. Studies to optimize ventilation cooling airflow rate (a user input of the NightBreeze control) show that a ventilation rate of about 1200 CFM results in the lowest annual energy use in all zones but Climate Zone 4, where 800 CFM results in lower energy use. However, a higher ventilation rate can preclude the need for air conditioning in this climate zone. Analysis of the Title 24 standard house design indicates the optimal ventilation rate is reasonably independent of house design.

To facilitate optimal user settings of ventilation airflow rate, a simple multiplier to determine ventilation rate from house floor area is suggested. Using the results from this

[8] The NightBreeze control allows the installer to select the ventilation rate. The blower and controls are configured to provide a minimum ventilation rate of 200 CFM, so the fan operates for about 18 minutes of each hour to meet the 60 CFM average ventilation rate if no heating is required. If heating is required during the hour, no additional fan energy is used since the damper opens to introduce fresh air concurrent with blower operation for heating.

report, this value should be 0.6 CFM per square foot in all climate zones. A value of 0.4 CFM per square foot could be applied in Climate Zone 4 if air conditioning is installed.

APPENDIX

Energy & Operating Cost Evaluation of Residential Mechanical Pre-Cooling in PG&E Territory

Report Issued: August 22, 2003

Prepared by: Davis Energy Group, Inc.
123 C Street
Davis, CA 95616

1 Background

In Pacific Gas and Electric (PG&E) Company service territory, the standard "flat" E-1 electric rate penalizes consumption with an escalating five-tier rate structure. An alternative time-of-use (TOU) rate (E-7) includes a tiered rate structure as well as a strong incentive to minimize on-peak electrical consumption. Since air conditioning is the principal on-peak load for most customers, the E-7 rate offers an opportunity for saving homeowners money by shifting cooling operation to lower cost off-peak hours.

2 Objectives

The Beutler Corporation, the largest residential HVAC contractor in Northern California, commissioned this study to assess the viability of pre-cooling houses during the morning off-peak hours as a means to minimizing on-peak cooling operation and annual cooling costs. The key to minimizing cooling costs relies on utilizing the PG&E E-7 TOU rate. Specific project objectives include the following:

- Develop detailed calibrated DOE-2 computer models for two recently built homes
- Determine utility bills for "typical" base case cooling system operation (E-1 and E-7)
- Evaluate various air conditioner pre-cooling and night mechanical ventilation options to determine the most cost-effective thermostat control option in typical Central Valley climates
- Convey project methodology and results

3 Methodology

A calibrated, hourly simulation model is one of the best ways to develop projections of how a house responds to climate, occupants, and thermostat control. The calibration step is vital as it brings simulation results better in-line with actual house performance. In this study we utilized data from two recent projects where detailed monitoring data were collected over many summer months. Data included indoor and outdoor temperatures, HVAC power, and numerous other datapoints, all collected on 15-minute intervals.

The basic goal in the calibration step was to generate projected indoor temperature profiles that closely match the monitored data. Typically homeowners do not open windows for ventilation during sleeping hours due to security and noise concerns[9]. With windows closed, a house will cool off more slowly than a ventilated house. On an average summer night, indoor temperatures may fall only a degree or two without the benefit of natural ventilation. At sunrise, solar gains through the windows and building envelope thermal gains quickly reverse the nighttime cooling trend. Without mechanical cooling during the afternoon period, indoor temperatures will often rise until 8 or 9 PM as the attic continues to dump heat to conditioned space below.

For this study, two houses were evaluated using the DOE-2 hourly simulation. These houses were selected because detailed monitoring data were available for use in calibrating the computer models. Table 1 summarizes the characteristics of the two

[9] For homeowners in the greater Sacramento area, especially westward towards San Francisco, lack of natural ventilation results in significantly higher cooling energy usage.

houses. House #1 can be considered fairly typical new construction, while House #2 incorporates additional energy measures improving the overall cooling season efficiency relative to House #1. This range in construction characteristics was evaluated to assess sensitivity of the simulation results.

Table 1: House Characteristics

Parameter	House #1	House #2
Year Constructed	1999	2002
Location	Dublin, CA	Livermore, CA
Floor Area	2,171	3,080
# of stories	2	1
Ventilation Strategy	None	NightBreeze
Cooling measures exceeding typical construction practice	None	Low-e2 glazing, Attic radiant barrier, Trellis window shading

Table 2 summarizes the two electric rates evaluated in this study. The standard E-1 rate was used for the reference case and the voluntary E-7 time-of-use (TOU) rate was used to evaluate pre-cooling options. Both rates feature tiered rate structures with increasing "per kWh" charges as usage increases. The TOU rate provides a distinction between winter and summer usage, as well as on-peak and off-peak[10].

Table 2: PG&E Residential Electric Rates

	Standard	Time of Use Rate E-7*			
	Rate	Winter		Summer	
Tier	E-1	On-peak	Off-peak	On-peak	Off-peak
1: up to baseline	$0.12589	$0.10904	$0.08119	$0.30792	$0.07783
2: 130% of baseline	$0.14321	$0.12636	$0.09851	$0.32524	$0.09515
3: 200% of baseline	$0.17713	$0.16028	$0.13243	$0.35916	$0.12907
4: 300% of baseline	$0.22106	$0.20421	$0.17636	$0.40309	$0.17300
5: > 300%	$0.24094	$0.22409	$0.19624	$0.42297	$0.19288

* E-7 requires a one-time meter charge of $277

The E-7 rate more closely reflects the true cost of electric service with high costs during summer on-peak and low costs during off-peak hours. The approximately 3:1 ratio of summer on-peak to off-peak rates provides a strong economic incentive to keeping usage off-peak. Three ways to achieve this are by actively keeping on-peak non-HVAC usage (laundry, pool pumps, etc.) to a minimum, installing a photovoltaic system (which provides the greatest output during peak hours), and by using the air conditioner to pre-cool the house prior to the peak period.

Figures 1 and 2 plot monitored hourly indoor temperature changes for two recently constructed houses described in Table 1. The data represents only days when the air

[10] Winter is defined as November 1 – April 30 and on-peak is weekdays noon to 6 PM (all year).

conditioner was not used and is therefore useful to characterize the thermal response of indoor temperature to varying outdoor conditions. Data are only shown for days when the maximum temperature exceeds 89°F, an arbitrary cut-off for conditions when air conditioning will typically be used. The data is further disaggregated into hot days (days with temperatures exceeding 100ºF) and moderate days (days with high temperatures between 89ºF and 99ºF). House #1 utilized little or no natural ventilation and #2 had the NightBreeze mechanical ventilation system. The nighttime cooling for the non-ventilated house averaged about 0.3 to 0.4°F per hour. Around sunrise the cooling trend reverses and the indoor temperature rise approaches ~1°F per hour by Noon.

Figure 1: Indoor Temperature Variations Without AC (House #1)

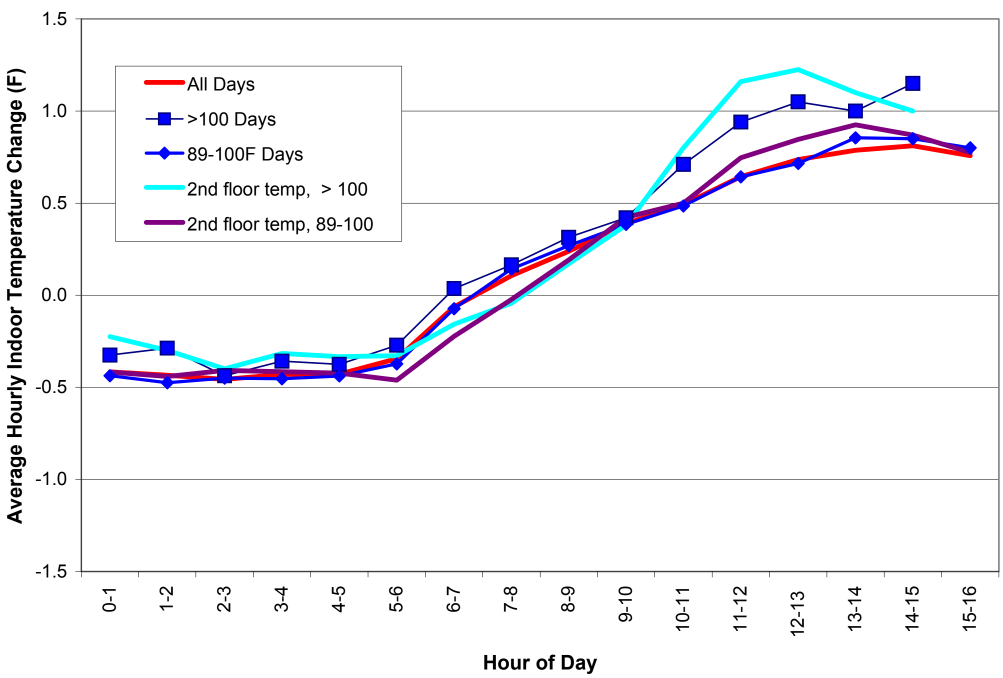
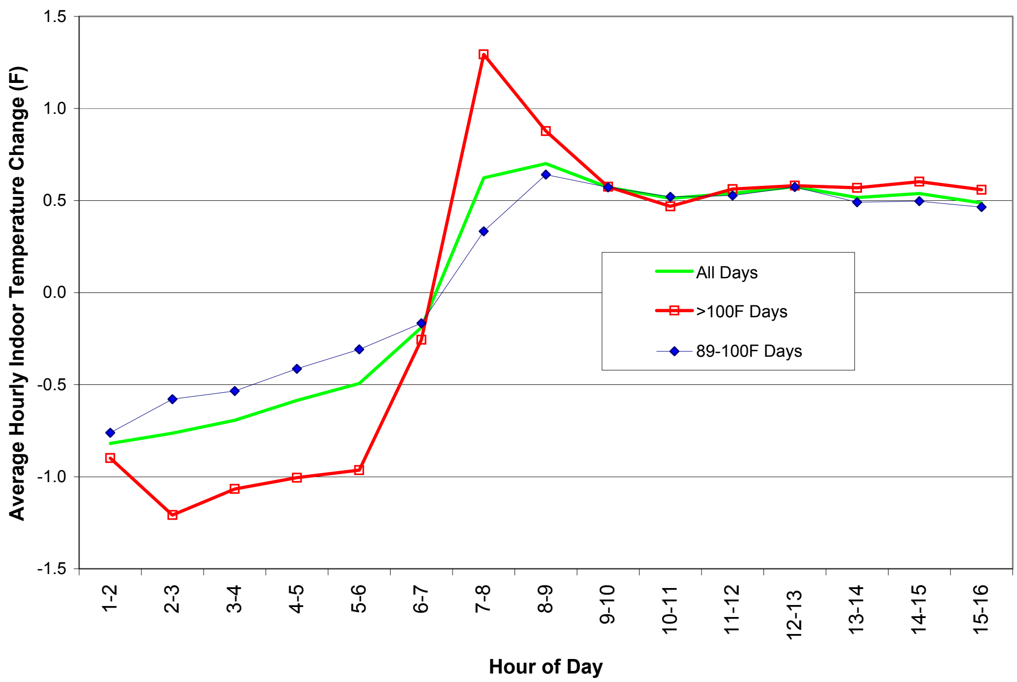


Figure 2 plots data for the more efficient house with the NightBreeze ventilation cooling system. Early morning "cool down" is approximately double that of the other houses, and is even more pronounced on the hotter days where the ventilation system is working harder to lower indoor temperatures. Daytime temperature rises are lower with House #2 due to the more efficient building envelope and the milder Livermore climate. The plots for Houses #1 and #2 were used in the DOE-2 model calibration efforts.

Figure 2: Hourly Indoor Temperature Variations Without AC (House #2)



Once the models were calibrated with the monitoring data, a series of runs were completed to identify typical base case cooling consumption (and monthly electric bills) and also to evaluate pre-cooling options. A standard cooling setpoint of 78°F was assumed in the base case and during the on-peak period for the pre-cooling runs. Table 3 summarizes the various pre-cooling strategies evaluated. This "basic" control strategy specifies a lower fixed temperature setting during the time period immediately preceding the peak period. This range of time periods and setpoints was evaluated to identify the most cost-effective pre-cooling option under the E-7 rate structure. These evaluations were completed for both houses and for two climate zones (Sacramento and Fresno). The SmartPrecool listing in Table 3 utilizes logic in the NightBreeze ventilation control to determine the lower limit target for mechanical pre-cooling. This "smarter" option sets a target which may be lower on very hot days, but would certainly be higher than the "basic" fixed setting control on mild days. Finally the last three options in Table 4 combine the optimal compressor pre-cooling scenario with various night ventilation configurations. All three night ventilation options assumed NightBreeze target temperature predictive capabilities. The first, SmartVent1, utilized a standard permanent split capacitor (PSC) blower motor (operating at 0.5 Watts per cfm), SmartVent2 substituted a more efficient electronically commutated motor (ECM), and the third utilized NightBreeze control logic to allow the ECM motor to operate at greater efficiency in variable speed mode.

Since this analysis is comparing conventional cooling system operation under the standard E-1 rate to pre-cooling scenarios under the E-7 rate, it is important to accurately estimate typical non-HVAC electrical consumption to arrive at a correct total annual electric cost. For this analysis, non-HVAC electrical loads were developed based on typical usage patterns for lighting, appliances, TV/audio/computer, and miscellaneous household consumption. On an annual basis, 5,275 kWh of non-HVAC usage is assumed. Table 4 summarizes the assumed disaggregation of the non-HVAC use. Overall, non-HVAC usage is assumed to be 19% on-peak. The breakdown will vary with how the house is occupied and the type of energy consuming features installed.

Table 3: Summary of Pre-Cooling Cases Evaluated

Case	Pre-cooling Setpoint	Time Setpoint In Effect	Comments
70-6	70°F	6 AM to Noon	
72-6	72°F	"	
74-6	74°F	"	
70-8	70°F	8 AM to Noon	
72-8	72°F	"	
74-8	74°F	"	
70-10	70°F	10 AM to Noon	
72-10	72°F	"	
74-10	74°F	"	
SmartPrecool	Variable	Optimal	Utilizes NightBreeze lower limit logic for setting daily AC cooling target
Options with natural ventilation and optimal pre-cooling			
SmartVent1	Optimal	Optimal	SmartVent with standard PSC motor
SmartVent2	"	"	SmartVent w/ECM motor (fixed speed)
NightBreeze	"	"	Variable speed ECM motor

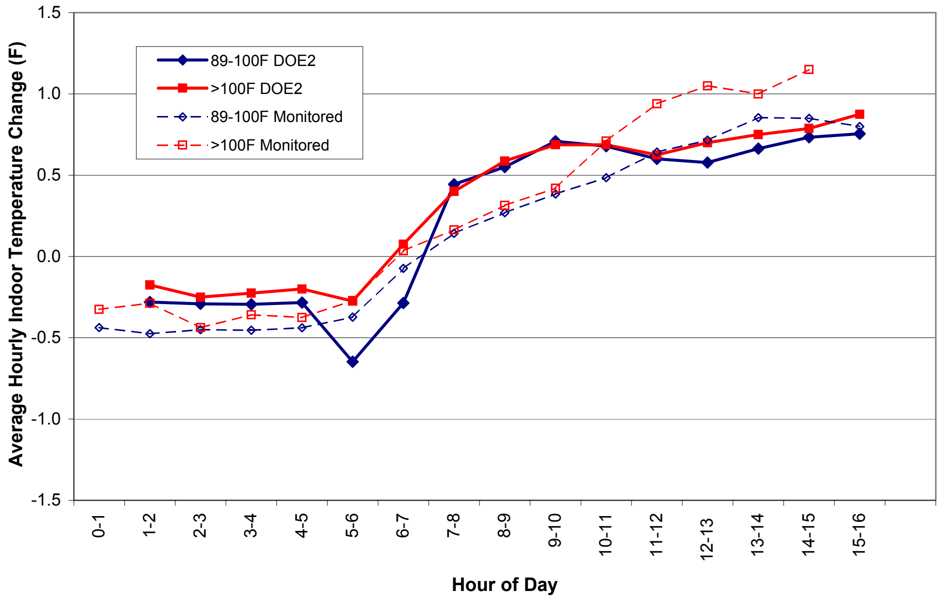
Table 4: Non-HVAC Usage Breakdown

End Use	Percent of Total Non-HVAC Usage	On-peak Usage Percentage
Appliances	39%	28%
Lighting	29%	11%
TV/computer	17%	18%
Miscellaneous	15%	18%

4 Results

DOE-2 models were completed for Houses #1 and #2. Indoor temperature projections from initial run results were compared to the monitoring data. For both cases, additional internal mass was needed to improve the fit between monitored results and simulation projections. The added mass affects the temperature swings by delaying and moderating the post-sunrise temperature rise and by moderating the evening temperature fall. The added mass is needed both to better mimic reality and to compensate for the absence of an attic in the DOE-2 models[11]. Figure 3 compares the results of the calibration effort for House #1. In general, the DOE-2 projections fit fairly well with the monitored data, considering that there are numerous random factors affecting real world operation. The fit for House #2 is shown in Figure 4.

Figure 3: Comparison of Monitored and Simulated Temperature Variations (House #1)



The set of parametrics shown in Table 3 were run for each house in each of the two climate zones (Sacramento and Fresno)[12]. House #1 results in Table 5 indicate the "basic 72-6" setting (72°F pre-cooling target temperature from 6 AM to Noon) was the most cost-effective pre-cool option for both Sacramento and Fresno climates. For the "base case" runs, switching to the E-7 rate had little impact in Sacramento but resulted in $51 higher electric bills in Fresno, presumably due to the greater fraction of HVAC operation during the expensive summer on-peak period. Optimal "basic 72-6" pre-cooling resulted in about $120-$160 annual savings (2 year payback for TOU meter). Adding mechanical ventilation significantly roughly doubled the savings relative to the non-ventilated pre-cool scenario. Use of more efficient (and more costly) ECM motors further improves the savings. Additional savings of 7-12% are achieved when the night ventilation control allows the ECM motor to operate in a fully variable speed mode.

[11] Attics are difficult to model accurately with DOE-2. The impact of an attic on indoor temperature variations is significant. It serves as a thermal capacitor both in the morning (as it heats up) and the evening (as it continues to dump heat to the house while the outdoor temperature falls off).
[12] Detailed summary tables are included in the Appendix.

Figure 4: Comparison of Monitored and Simulated Temperature Variations (House #2)

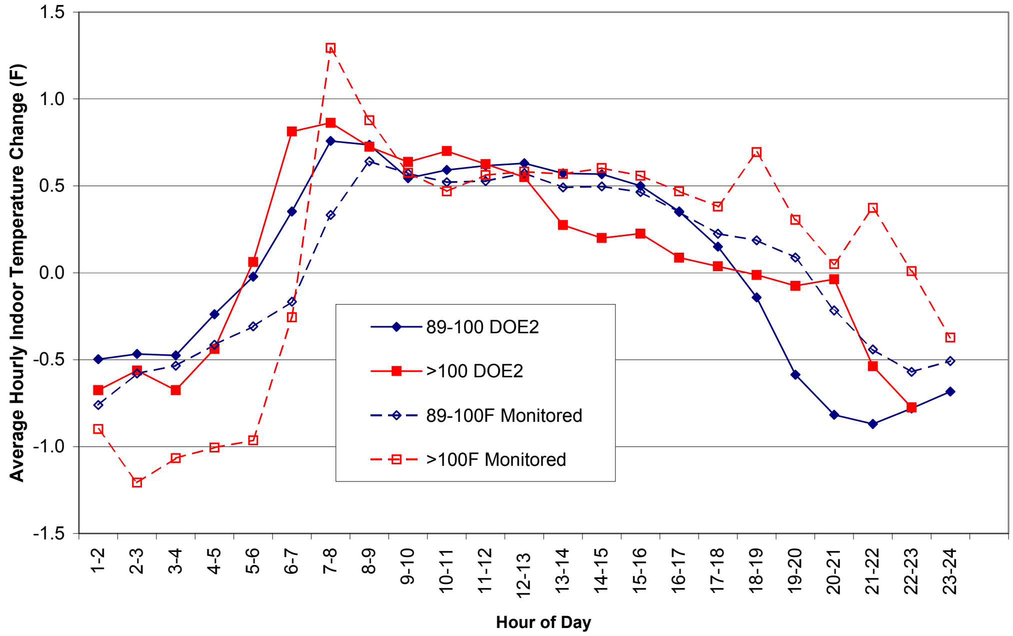


Table 5: House #1 Results Summary

Analysis Case	HVAC Energy Use (kWh) Total	On-Peak	Off-Peak	Total Cost/year Electric	Cost Savings
Sacramento					
Base Case (E-1 Rate)	2,295			$ 1,037	N/a
Base Case (E-7 Rate)	2,295	950	1,345	$ 1,034	$ 3
"Basic" Precool (72-6)	2,779	149	2,630	$ 915	$ 123
"Smart" Precool	2,725	155	2,570	$ 909	$ 128
SmartVent1 w/ PSC	1,911	83	1,828	$ 776	$ 271
SmartVent2 w/ ECM fixed	1,172	56	1,115	$ 688	$ 325
NightBreeze w/ ECM var	1,004	56	948	$ 671	$ 367
Fresno					
Base Case (E-1 Rate)	4,742			$ 1,511	N/a
Base Case (E-7 Rate)	4,742	1,731	3,010	$ 1,562	($ 51)
"Basic" Precool (72-6)	5,068	465	4,603	$ 1,353	$ 158
"Smart" Precool	5,227	303	2,570	$ 1,345	$ 167
SmartVent1 w/ PSC	4,280	299	1,828	$ 1,195	$ 316
SmartVent2 w/ ECM fixed	3,691	278	1,115	$ 1,105	$ 406
NightBreeze w/ ECM var	3,437	278	948	$ 1,077	$ 434

Table 6 summarizes results for the single-story House #2. For both Sacramento and Fresno climates, base case cooling energy use is about 700 kWh lower than for House #1. Interestingly, the more efficient house design results in the "basic 74-6" pre-cool strategy being the most cost-effective. This makes sense since a more efficient structure should not require as much pre-cooling to get through the peak period. Savings are consistently lower for House #2, although the impact is less pronounced in the hotter Fresno climate.

Table 6: House #2 Results Summary

Analysis Case	HVAC Energy Use (kWh) Total	On-Peak	Off-Peak	Total Cost/year Electric	Cost Savings
Sacramento					
Base Case (E-1 Rate)	1,607			$ 916	N/a
Base Case (E-7 Rate)	1,607	649	958	$ 877	$ 39
“Basic” Precool (74-6)	1,951	164	1,786	$ 806	$ 110
“Smart” Precool	1,897	170	1,726	$ 801	$ 116
SmartVent1 w/ PSC	1,730	68	1,662	$ 750	$ 166
SmartVent2 w/ ECM fixed	1,463	53	1,410	$ 719	$ 197
NightBreeze w/ ECM var	729	53	676	$ 637	$ 279
Fresno					
Base Case (E-1 Rate)	4,103			$ 1,418	N/a
Base Case (E-7 Rate)	4,103	1,528	2,575	$ 1,459	($ 41)
“Basic” Precool (74-6)	4,397	563	3,835	$ 1,278	$ 140
“Smart” Precool	4,343	569	3,775	$ 1,273	$ 146
SmartVent1 w/ PSC	3,818	305	3,513	$ 1,122	$ 296
SmartVent2 w/ ECM fixed	3,380	273	3,107	$ 1,051	$ 367
NightBreeze w/ ECM var	2,775	273	2,502	$ 983	$ 435

Figures 5-8 plot annual cooling energy use and total electric bill for the various scenarios evaluated. Although both “basic” and “smart” pre-cool strategies increase cooling energy usage, the shifting from on-peak to off-peak results in lower utility bills under the E-7 rate. Mechanical night ventilation offers significant benefit in all cases.

The analysis completed here is based on an “average” residential customer. This profile assumes a fixed 78°F cooling setpoint, little or no natural ventilation, and non-HVAC energy usage with a 19% on-peak, 81% off-peak distribution. Deviations from these typical assumptions will affect the projected savings. One area that was evaluated was how sensitive the savings numbers are to the assumed distribution of non-HVAC energy use. Our base case assumption assumes that 19% of the 5,275 kWh (~1,000 kWh) non-HVAC usage occurs during on-peak periods. If actual household usage is 25% on-peak (equal to shifting 25 kWh per month from off-peak to on-peak), the annual electric bill increase will be about $80. A corresponding shift from on-peak to off-peak would reduce the bill by $80. The importance of this is that the homeowner needs to be educated on the significance of monitoring on-peak consumption, if they are to realize cost savings from implementing a pre-cooling strategy. A customer who insists on on-peak pool pumping will clearly throw away any potential savings accruing from pre-cooling.

Figure 5: Comparison of Sacramento Pre-cooling Options (House #1)

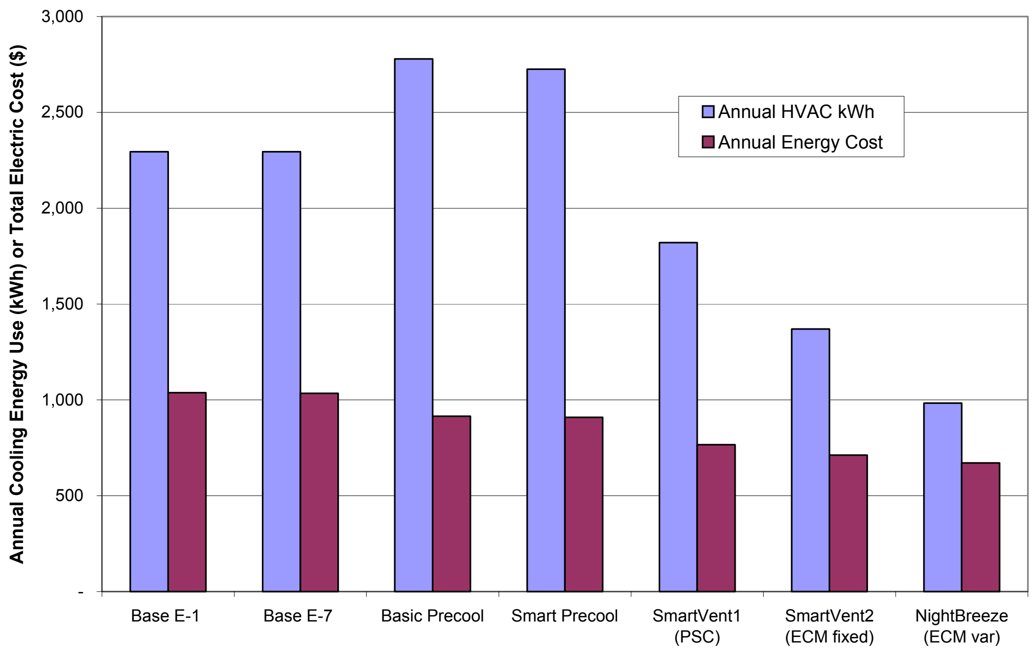


Figure 6: Comparison of Fresno Pre-cooling Options (House #1)

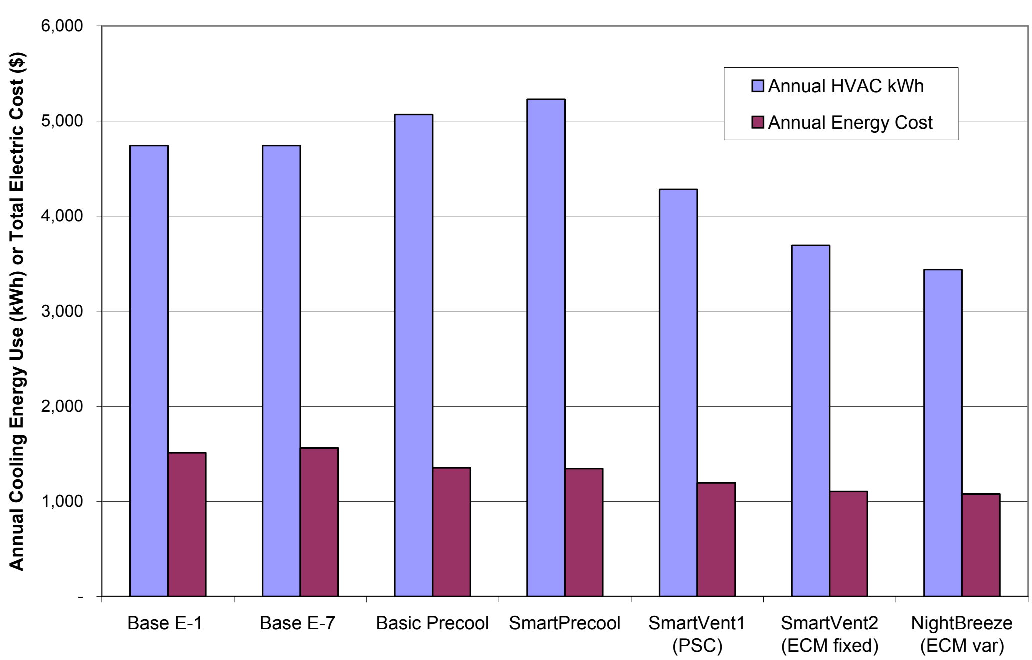


Figure 7: Comparison of Sacramento Pre-Cooling Options (House #2)

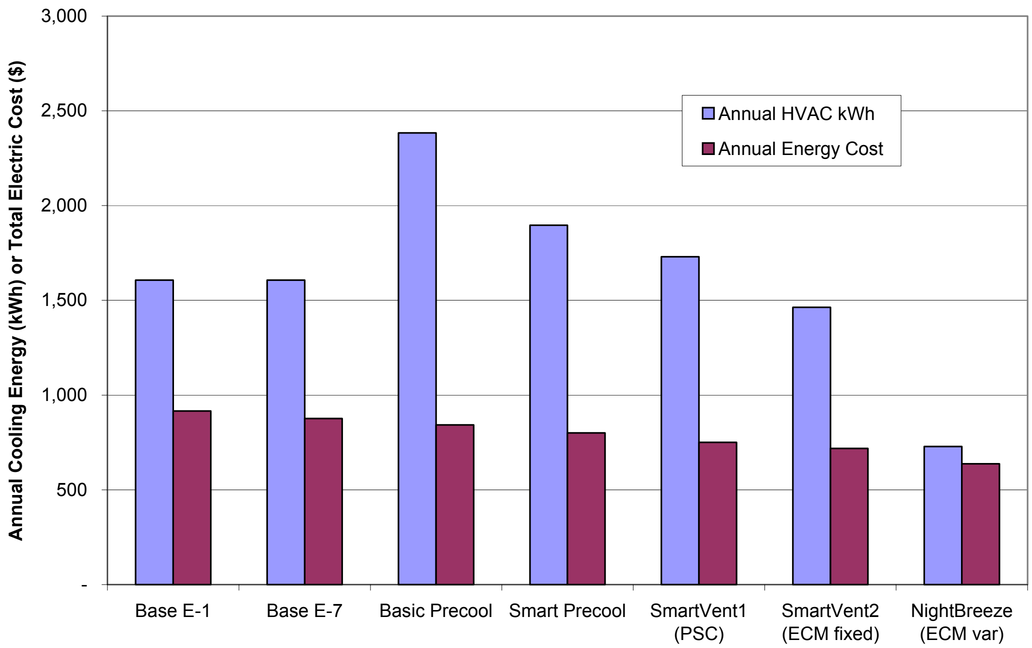
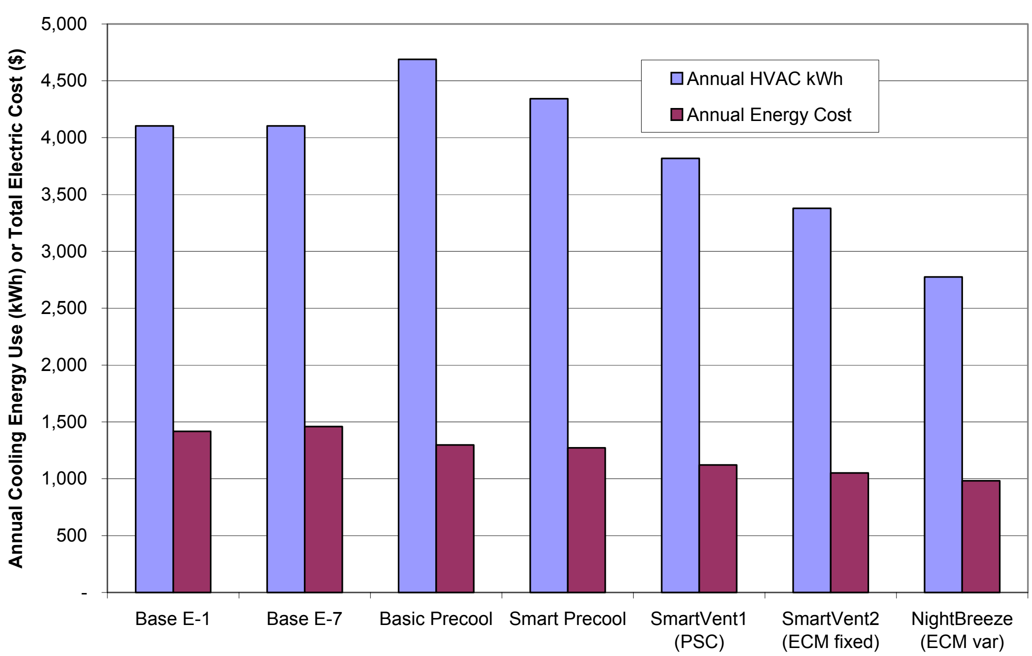


Figure 8: Comparison of Fresno Pre-cooling Options (House #2)



4.1 Conclusions

In Pacific Gas and Electric Company service territory, the combination of TOU electric rates and mechanical pre-cooling will result in significant homeowner financial benefit, provided they make reasonable efforts to control their on-peak non-HVAC electrical consumption. Under typical usage profiles, the $277 TOU meter cost (required under PG&E's E-7 rate) will be paid for within two years. Incorporating mechanical ventilation with the air conditioner pre-cooling will more than double the projected savings. Replacing the PSC motor in the air handler with an ECM will generate an additional $50 to $140 per year savings over the basic Smart Vent system. Providing smart controls allowing the ECM motor to operate in variable speed mode increases savings by an additional 10%.

Projected savings are approximately 20-30% higher in the hotter Fresno climate than in Sacramento. Factors affecting projected savings include:

1. <u>Cooling setpoint</u>: A lower standard setpoint reduces the ability to do off-peak pre-cooling
2. <u>Natural ventilation</u>: Homeowners who use natural ventilation (or whole house fans) will have lower savings
3. <u>Energy usage profile</u>: Homeowners who deviate significantly from the assumed 19% on-peak non-HVAC usage will be affected by the E-7 time-of-use rate. With summer on-peak "per kWh" rates three to four times higher than off-peak, intelligent homeowner control can improve the savings projection. Conversely, lack of homeowner awareness (e.g. on-peak pool pumping) could have devastating results.

Pre-cooling coupled with night ventilation offers the greatest cost savings potential, although the cost of integrating SmartVent or NightBreeze needs to be considered.

ALTERNATIVES TO COMPRESSOR COOLING PROJECT

Attachment 1: Air Handler and Damper Test Reports

**INTEGRATED HEATING, VENTILATION,
AND COOLING UNIT TEST REPORT
Alternatives to Compressor Cooling Project
PIER Contract #500-98-024**

1 INTRODUCTION

1.1 Background

One of the goals of the Alternatives to Compressor Cooling Project is to develop a residential air handler that includes a variable speed blower and that integrates hot water heating and direct expansion cooling coils, and a damper that draws in outdoor air for ventilation cooling. The purpose of this project task was to develop test data needed to determine whether the performance of the prototype HVC unit meets design specifications. Previous testing evaluated damper performance; HVC unit tests combined the damper in the air flow path, but did not further test damper functions. Tests were completed by the Pacific Gas & Electric Company (PG&E) Technical and Environmental Services Center (TES), and evaluation and reporting of test data was completed by Davis Energy Group (DEG).

1.2 Description of the Component Tested

The component tested is prototype air handler designed under project task 2.1.5. The air handler was assembled using a Lau DD12-12A blower, a G.E. ICM2 variable speed motor, a custom manufactured heating-cooling coil, and a custom designed cabinet. The air handler also included a circulating pump and controls to operate the blower motor, pump, and damper. Controls testing was not a part of this task.

1.3 Rationale for Testing

The intended outcome of air handler development is a prototype that is essentially market ready. This requires development of heating and cooling performance data for the coil, and blower performance data that will be used in technical and marketing literature. In addition, blower test data is needed to complete programming of the motor controller.

The coil employed in the air handler includes two rows for hot water heating and two rows for refrigerant cooling. Heating and cooling rows alternate and share the same fins, so that each two row coil has the equivalent fin area of a four row coil. The coil was designed to produce specific heating and cooling capacities. Since coil design software cannot model the shared fins, coil performance data must be determined empirically.

The G.E. ICM2 blower motor used in the air handler is delivered from the factory in a "regulated torque" configuration. In this configuration the motor performs similarly to an induction motor, with airflow varying significantly with static pressure. To enable field selection of the proper air flow rates it was necessary to re-program the motor in a "regulated CFM" configuration that allows the control to specify an air flow rate that the motor will maintain over a wide range of static pressures. Testing was completed to identify a set of blower constants required for motor programming.

2 TEST OBJECTIVES, METHODS, AND PREDICTED PERFORMANCE

2.1 Test Objectives

The objectives of the testing were to develop heating and cooling performance data for the coil, motor programming data, blower performance curves, and electrical data. Specific performance values evaluated in testing included:

- Blower air flow and RPM over a range of torque values
- Coil sensible and latent cooling capacity at specified conditions
- Coil heating capacity at specified conditions
- Blower air flow (programmed motor) over a range of air flow rates and static pressures
- Blower power vs. air flow
- Maximum system amps (blower at maximum speed)

2.2 Predicted Performance

Total Air Flow and RPM vs. Torque
The purpose of these tests is not to verify predictions but to determine performance for motor programming purposes.

Cooling Capacity
The ACC prototype inland climate house is projected to require less than two tons of cooling capacity in most California locations (Huang 1999). The cooling coil, as designed, has a sensible capacity of 22,305 Btuh and a total capacity of 28,956 Btuh at 80º F entering dry bulb temperature, 67ºF entering wet bulb temperature, 1200 cfm air flow, and 45ºF evaporating temperature. Tests were completed to verify that coil capacities are equal to or greater than these values under conditions similar to those indicated.

Heating Capacity
The ACC prototype houses are also projected to have low heating loads. Coil design calculations for heating project a capacity of 47,697 Btuh at 65ºF entering air temperature, 140º entering water temperature, 1200 cfm air flow, and 4 gpm water flow.

Ventilation Air Flow and Maximum External Static Pressure
The air flow target for ventilation cooling is 2000 cfm. Based on blower and motor performance ratings, the blower can deliver 2000 cfm at 1.4" static pressure. The system effect losses calculated using AMCA 201-90 were estimated to be 0.30" w.c. at 2000 cfm, and the coil loss at this air flow is 0.27" w.c., resulting in a total predicted "internal" pressure drop of 0.57", leaving 0.83" external static pressure available. The filter adds about 0.3", so the unit, with damper and filter in place, was expected to deliver about 2000 cfm at an external static pressure of 0.5".

Blower Power and Current
Rated maximum power consumption for the G.E. 1 H.P. ICM2 motor is 1050 Watts and input current is 12.8 Amps at 120 VAC. Power at lower torque (than the 80 oz.ft. maximum) will be empirically determined over a range of speeds.

2.3 Technical Approach And Test Procedures

Approach and General Procedures
Tests were completed at PG&E's TES test facility between August and October 2000. Tests involving determination of air flow rates used equipment and methods conforming to AMCA Standard 210-85. The technical approach and detailed test procedures are described in the Air Handler Test Plan.

Cooling Tests
A Carrier Model 38TDA036-30 two-speed condensing unit was used as a cooling source for coil cooling tests. Tests were completed at both low and high speed to evaluate coil performance at a range of evaporator temperatures. Based on previous tests with a conventional "A" coil (Carrier Model CT6448-M210), the condensing unit produced approximately 2 tons of cooling at low speed and 3 tons at high speed.

Heating Tests
A Keltec Accutemp tankless electric water heater (240 V, 18 kW) served as the heat source for the heating tests. Water was recirculated between the water heater and the coil using the pump internal to the air handler, plus an external booster pump. The water flow rate averaged 3.7 gpm during the tests.

2.4 Facilities and Personnel

All tests were completed at the Pacific Gas & Electric Company Technical and Ecological Services test facility located in San Ramon, California. Testing was completed by Jim Yang, and was coordinated by Paul Miller.

3 RESULTS

3.1 Blower Curve Development

Tests to develop data necessary for reprogramming the motor from regulated torque to regulated airflow operation were completed by mid August. Test data collected at an external static pressure of 0.25" w.c. were selected for motor blower curve development. Figure 1 shows these RPM, PWM, and air flow data as they were entered into the G.E. KFIX program, which calculates constants for the equation that relates torque, RPM, and airflow. The calculated constants (A1-A4) are indicated above the tabular data.

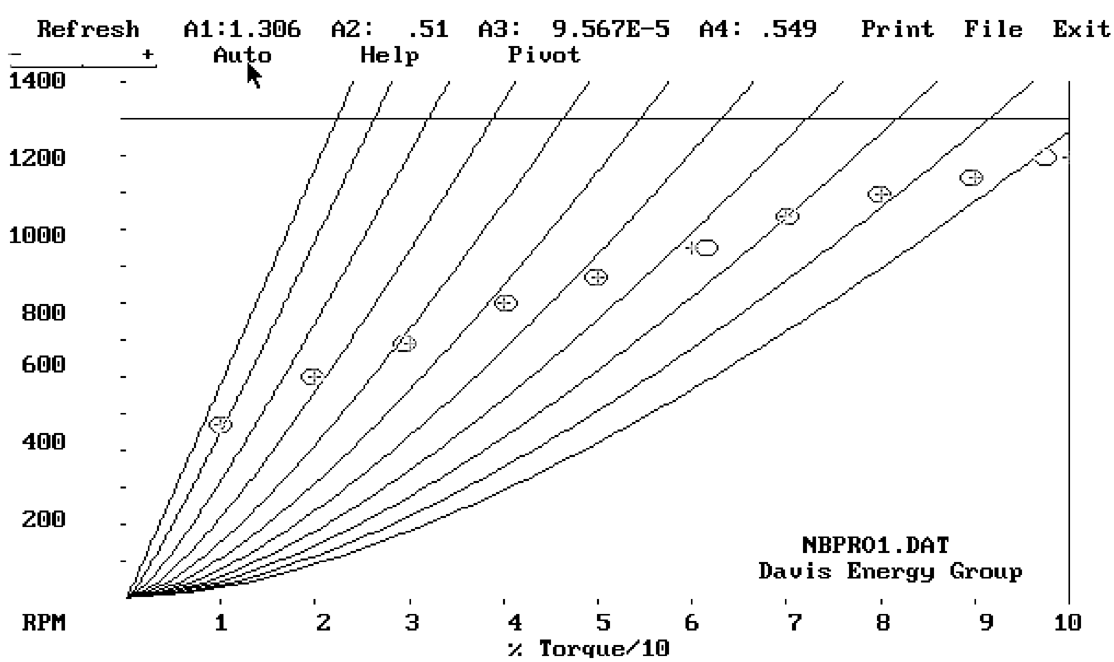
The KFIX program produces a graph that indicates the validity of the data from which the blower constants are produced, shown in Figure 2. The solid curves are lines of constant airflow demand (from 0 to 100%). Since a maximum air flow of 2400 cfm was used to develop the blower constants, the rightmost curve represents the combination of torque and RPM values that would be needed to maintain a constant 2400 cfm over a range of static pressures. The + symbols are actual torque values for the RPM and airflow test values entered. The O symbols are the torque that would result at the same

RPM using the calculated constants. If the O's and +'s line up, the motor constants will produce the correct air flow. As Figure 2 shows, the alignment is acceptable.

Figure 1: KFIX Data Entries and Motor Programming Constants

```
+----------------------------------------------------------------------+
¦                                                                      ¦
¦      ******** GE ICM-2  Airflow Adjustment Program - V6.1 ********   ¦
¦                                                                      ¦
+----------------------------------------------------------------------+
+----------------------------------------------------------------------+
¦ (F) File Utilities                                                   ¦
¦+------------------------------------------------------¦NBPRO1.DAT  ¦+¦
¦¦                                                                    ¦¦
¦¦1   Davis Energy Group                                              ¦¦
¦¦2   MaxCFM   2400                                                   ¦¦
¦¦3     A1 =  1.200   A2 =  0.010   A3 =   7.000E-6   A4 =  0.940     ¦¦
¦¦4    RPM    Pwm/Ob CFM    Color                                     ¦¦
¦¦5      470  0.100    216  1.000                                     ¦¦
¦¦6      601  0.200    659  1.000                                     ¦¦
¦¦7      692  0.300    990  1.000                                     ¦¦
¦¦8      801  0.400   1272  1.000                                     ¦¦
¦¦9      868  0.500   1508  1.000                                     ¦¦
¦¦10     951  0.600   1776  1.000                                     ¦¦
¦¦11    1033  0.700   1929  1.000                                     ¦¦
¦¦12    1093  0.800   2116  1.000                                     ¦¦
¦¦13    1138  0.900   2315  1.000                                     ¦¦
¦¦14    1195  1.000   2418  1.000                                     ¦¦
¦¦15                                                                  ¦¦
++--------------------------------------------------------------------++
```

Figure 2: KFIX Motor Curves



3.2 Cooling Capacity Tests

Cooling capacity tests were repeated at least twice at each condition (air flow, entering wet bulb temperature, and evaporator temperature) and results were averaged. Since the tested conditions did not match the rating points precisely, a coil design program (Coils Plus Version 7.05) was used to normalize the results by adjusting the finned length of the coil until calculated performance matched the tested performance. This equivalent coil size was used to calculate performance at the normal rating points. Table 1 compares original performance estimates to normalized coil test results. Table 2 lists complete test results normalized to nominal rating conditions using the same method described above.

Table 1: Predicted vs. Measured Cooling Performance

	Total Capacity, Btuh	Sensible Capacity, Btuh
Predicted	28,957	22,306
Measured	23,610	19,544

Rating Conditions: Entering air dry bulb / wet bulb temperatures: 80/67
Air flow rate: 1200 cfm
Suction temperature: 45° F

Table 2: Cooling Performance at Nominal Rating Points

		80 Entering Dry Bulb 63 Entering Wet Bulb		80 Entering Dry Bulb 67 Entering Wet Bulb	
Suction Temp	CFM	Total Btuh	Sensible Btuh	Total Btuh	Sensible Btuh
40	800	20,954	18,814	23,661	16,403
45	800	16,610	16,610	19,414	14,836
40	1000	23,121	21,688	25,748	18,694
45	1000	18,830	18,830	21,022	16,987
40	1200	23,367	23,367	28,761	21,356
45	1200	20,446	20,446	23,610	19,544

Surprisingly, measured performance of the four row coil was about ½ ton lower than the predicted performance for a two row coil. Equivalent coil lengths were 67 to 78% of the tested coil length. Implications are that no value was gained from the shared fins, and/or that the coil design software is significantly inaccurate.

Though the reduced coil capacity is adequate to meet the Manual J cooling load for the Inland Climate prototype house, it is not adequate to meet cooling requirements for the Southern California prototype. To improve flexibility of application, these results point in the direction of using a separate cooling coil that can be sized to meet a broad range of building cooling requirements.

As Table 2 shows, an entering wet bulb temperature of 63°, which is probably more typical than 67° in California climates, results in no latent cooling at a 45° suction temperature, and minimal latent cooling at a 40° suction temperature. The actual measured latent fraction at 1216 cfm, 45.1° condensing temperature, and 62.8° entering wet bulb temperature was a negligible 1.4%. Lower latent fractions are favorable in that compressor energy use is reduced.

3.3 Heating Capacity Tests

The same technique for evaluating coil cooling performance was applied to heating test data. The three heating capacity measurements taken at each rating point were averaged and normalized to the rating points to develop the data reported in Tables 3 and 4. The same normalization methods were used for heating as described for cooling.

Contrary to cooling performance results, Table 3 shows that heating coil performance was better than predicted by the coil design software. The coil length had to be adjusted to from 103 to 125% of the actual coil length to match calculated coil performance to actual. Again, it is not known whether this improvement is attributable to the design of the coil (shared fins) or to software inaccuracy.

Table 4 lists coil heating performance normalized to air flow and water temperature rating points. All capacities are at 65°F entering air temperature and 3.7 gpm water flow, which is the flow rate used in all heating tests. Heating capacities are sufficient to meet heating requirements of all three prototype houses.

Table 3: Predicted vs. Measured Heating Performance

	Total Capacity, Btuh
Predicted	47,697
Measured	48,200

Rating Conditions: Entering air dry bulb temperature: 65
Air flow rate: 1200 cfm
Entering water temperature: 140° F
Water flow rate: 4 gpm

Table 4: Heating Performance at Nominal Rating Points

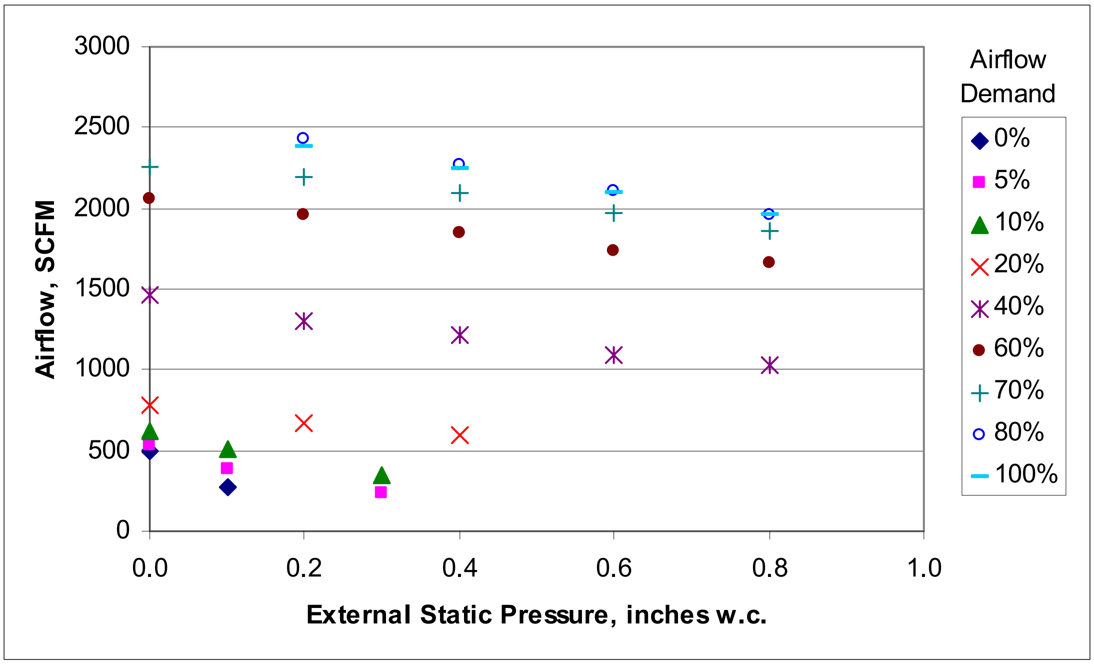
	Btuh Capacity at Entering Water Temperature		
CFM	130°	140°	150°
800	34,278	39,661	45,060
1000	37,479	43,398	49,344
1200	40,798	47,265	53,762

3.4 Ventilation Rate Test Results

The only ventilation rate performance target established in the test plan was the capability to deliver 2000 cfm at an external static pressure (ESP) of 0.5". However, it was also important to insure that the blower properly responds to programmed airflow demand, and to determine blower energy consumption. The latter is required for determining optimal control strategies.

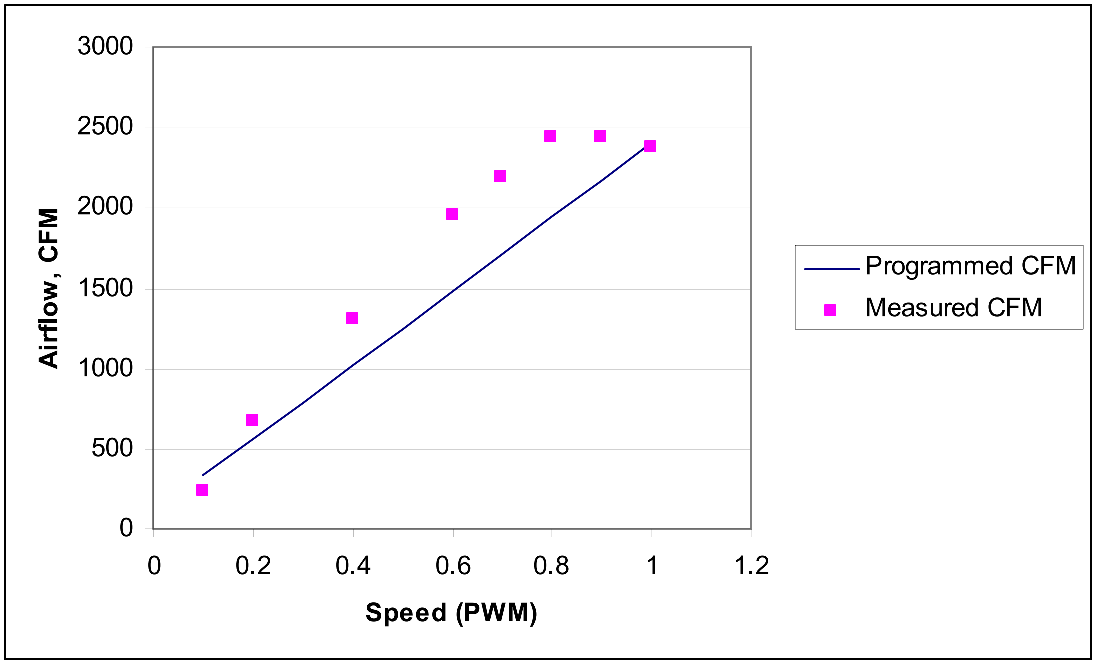
Figure 3 graphs airflow at a variety of static pressures and blower demand settings. These data were obtained following programming of the motor to "air flow regulation mode". In this mode the motor should produce airflow rates that are proportional to demand settings. Demand is selected by sending the motor a pulse width modulation (PWM) input that varies from 0 to 100%. Two phenomena are apparent from Figure 3: (1) the blower and motor easily meet the airflow target, delivering more than 2200 cfm at 0.5" ESP, and (2) the curves are not as flat as would be expected given the "regulated cfm" motor program. The airflow at each demand setting should not vary substantially with changing static pressure.

Figure 3: Air Handler Airflow vs. External Static Pressure



Motor programming (described in Section 3.1) included a minimum airflow setting of 100 cfm and a maximum of 2400 cfm. At 60% demand the blower should deliver 0.6 x 2300 + 100 = 1480 cfm. Referring Figure 3, the blower delivered 1740 cfm at 60% demand. To further investigate the response of the motor to airflow demand inputs, airflow was plotted versus demand at 0.2" external static pressure. The results are shown in Figure 4.

Figure 4: Airflow vs. Demand at 0.20” External Static Pressure

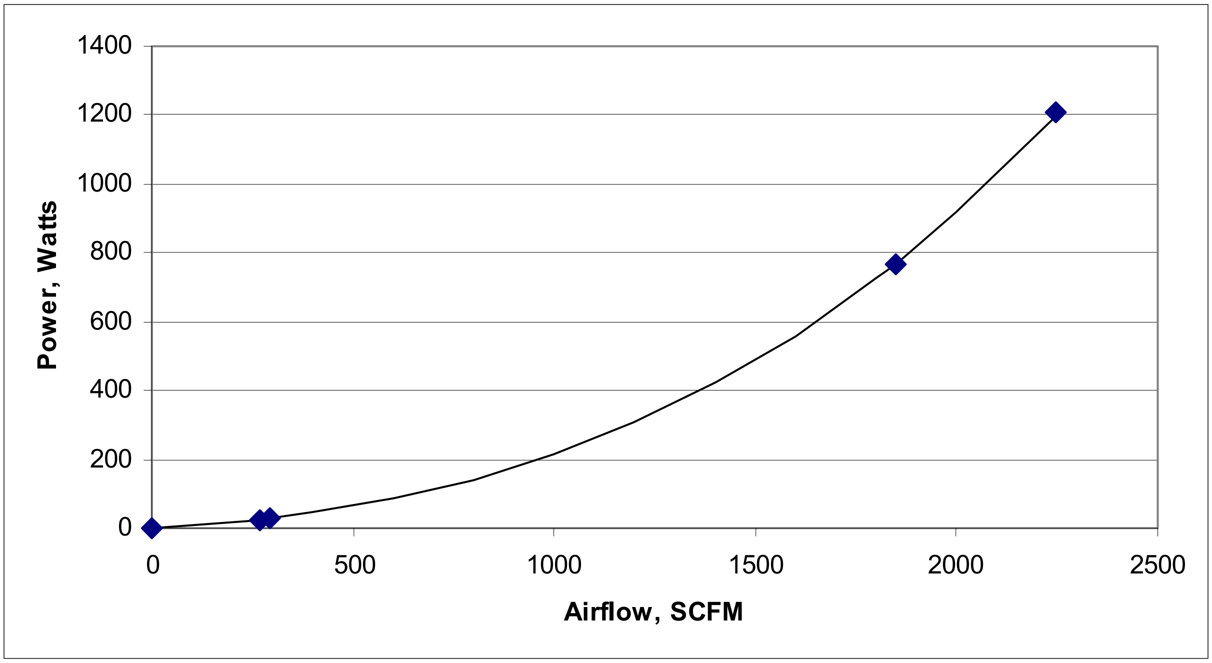


The solid line in Figure 4 shows how the motor would be expected to respond to varying airflow demand inputs. Over most of the demand range the blower delivered more airflow than it should have, given the motor program. High speed stalling of the fan blades accounts for the drop in airflow at speed demand greater than 0.8.. Assistance will be sought from the motor manufacturer to resolve this apparent motor programming problem.

Substantial test measurements were taken to determine fan power at various airflow rates and static pressures. For a system with fixed airflow-pressure drop characteristics such as typical ductwork, static pressure increases with the square of the airflow rate. To determine how power would vary in a typical variable speed air handler installation, a measured static pressure/airflow point of 0.4" external static pressure at 2332 cfm was used to define a characteristic duct system pressure drop curve. Then, test data that corresponded to the pressure drop curve were plotted against motor power to develop the curve shown in Figure 5. The discrete points on the curve are from test measurements, and the curve is a 3rd order polynomial curve fit of the measured data.

One planned use of the air handler is to provide fresh air ventilation by operating the fan at its lowest speed with the outside air damper open. For this reason, airflow rates and power consumption at the lowest fan speeds is of interest. Tests showed that the fan delivered 292 cfm against a static pressure of 0.1” and consumed 30 Watts. The resulting 0.1 W/cfm is half the power draw of the most efficient bathroom ventilator available (Panasonic FV-08). It will be necessary to cycle the fan to avoid ventilation in excess of that recommended by the proposed ASHRAE 62.2 standard.

Figure 5: Typical Power Consumption vs. Airflow



4 CONCLUSIONS

Tests of the prototype air handler resulted in the following findings:

- Performance of the cooling coil was about 18% lower than projected by coil engineering software at rating conditions.
- Performance of the heating coil was about 1% better than projected by coil engineering software at rating conditions.
- The air handler delivered about 10% more air volume than the projected 2000 cfm at 0.5" external static pressure.
- Tests of the blower after "regulated cfm" programming showed that airflow varied more than 20% over a 0 to 0.8" static pressure range.
- Air handler power-airflow curves were satisfactorily developed, and show that the unit can provide very efficient variable speed heating, ventilation cooling, and fresh air ventilation.

The prototype air handler, as designed, can meet heating and cooling requirements for the prototype inland climate house. Tests to determine the benefits of the integrated heating/cooling coil are inconclusive, primarily due to inaccuracies in engineering software. The performance advantage of the shared fins is probably negligible.

Depending on the actual loads of the houses selected for field testing, field test units may be designed with external cooling coils to allow more sizing flexibility. A two-row heating coil is likely to provide sufficient heating capacity for most applications, so air handler air pressure drop is not likely to be significantly compromised with the addition of an external cooling coil.

Additional work and assistance from General Electric is needed to resolve blower motor programming so as to improve the regulated air flow performance of the blower. DEG is currently collaborating with Enviromaster International Corporation (EMI) to assemble a pre-production prototype variable speed air handler that is likely to be used for the field test houses. The EMI prototype may have sufficiently different performance to warrant additional testing, which EMI can provide. Therefore, additional testing by PG&E TES to verify motor programming for the initial prototype is unnecessary.

DAMPER TEST REPORT
Alternatives to Compressor Cooling Project
PIER Contract #500-98-024

1. INTRODUCTION

1.1 Background

One of the goals of the Alternatives to Compressor Cooling Project is to develop a residential air handler that integrates a damper that draws in outdoor air for ventilation cooling. The purpose of this project task was to develop test data needed to determine the adequacy and performance of the selected damper in this application. Tests were completed by the Pacific Gas & Electric Company (PG&E) Technical and Environmental Services Center (TES), and evaluation and reporting of test data was completed by Davis Energy Group (DEG).

1.2 Description of the Component Tested

The component tested is an air damper manufactured by ZTECH, "SmartVent" Model No. 2030DD. The damper is produced as a residential economizer, and was selected to be a component of the Heating, Ventilation, and Cooling (HVC) unit to be developed under this PIER project.

1.3 Rationale for Testing

Damper assemblies used in commercial economizers are notoriously prone to failure of motors and/or linkages. The SmartVent damper design is distinct from other commercial dampers in that it uses a single damper blade and a direct-drive motor instead of multiple blades with linkages or worm-drive actuator. Testing was performed to determine damper lifetime, to determine pressure drop, and to determine its air leakage characteristics. This information was needed for developing system specifications and for identifying potential damper improvements.

Damper air leakage can be useful in that it contributes to indoor air quality, but an excessive amount will increase heating and cooling energy use by increasing infiltration during fan operation. Leakage information will be used to determine ventilation strategy. Excessive leakage will prompt a review of potential improvements to the damper seals.

The relief opening of the SmartVent damper is much smaller than the other air connections. Resistance to air flow through the relief could over-pressurize the house, causing difficulty opening doors (if no windows are open during fan operation), and increasing fan energy use. Tests are necessary to determine whether additional relief, for example a ceiling-mounted barometric damper, is needed.

1.4. Test Objectives and Predicted Performance

Performance values that need to be identified include:

- Minimum number of cycles without failure
- Leakage rate at corresponding pressures
- Pressure drop over a range of air flow rates

The damper should last as long as the 20-year typical lifetime of heating/cooling equipment (Butcher 1990). Since the damper is expected to cycle about 150 times per year, it should be able to tolerate in excess of 3000 cycles in accelerated testing.

A reasonable but arbitrary leakage target for the damper, while operating in heating or air conditioning mode, is 2% of the total design air flow of 1000 cfm, or 20 cfm at 10 Pa pressure. The objective of the leakage test is to determine damper leakage empirically.

Damper pressure drop information will be used to determine whether additional relief should be provided. There is no critical pressure drop value.

2. TEST METHODS

2.1 Test Facilities and General Procedures

All tests were completed at PG&E's TES test facility by Ken Gillespie. A log was maintained to document test conditions, the date and time of the tests, modifications of test procedures, and general observations. Air flow – pressure test data were transferred to Excel format and provided to DEG for analysis and reporting. Table 1 summarizes tests to be performed, their duration, and follow-up action.

Test	Duration	Repeat If	Remedial Action
Cycle test	Approx. 40 hours at 1 minute cycle time	Damper fails	Document, repair and re-test
Air leakage test	Sufficient to collect data (approx. 1 hour)	Leakage exceeds 20 cfm at 10 Pa.	Improve seals and re-test
Pressure drop test	Sufficient to collect data (approx. 1 hour)	Repeat with damper activated	None

2.2 Equipment and Materials

A ZTECH SmartVent Model 2030DD damper was delivered to PG&E TES with the following components attached for purposes of powering the damper, cycling the damper, and measuring the number of damper strokes:

> 24 VAC, 40 VA transformer
> Microswitch, Grainger 6A889
> Counter, Grainger 1A789
> Repeat cycle timer, Grainger 4KN14

Components were connected as shown in Figure 1.

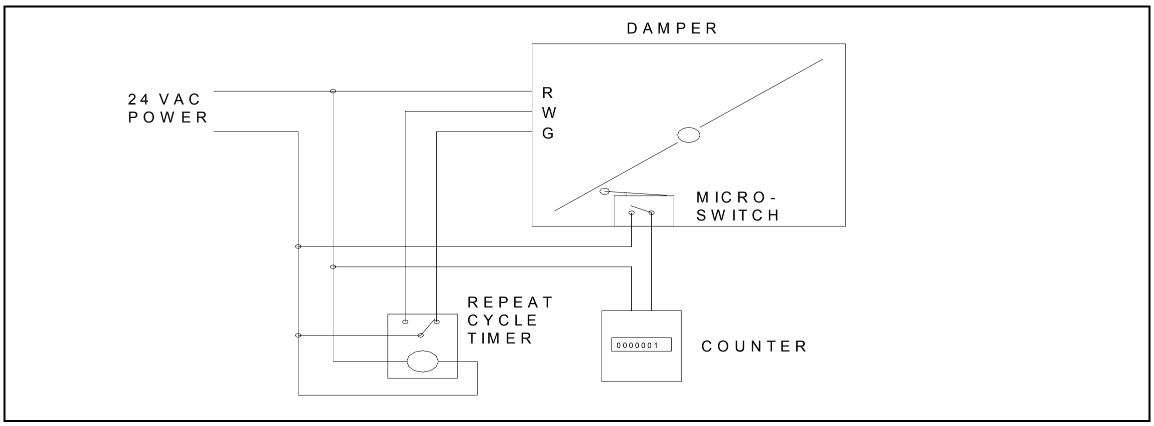


Figure 1: Damper Wiring Diagram

2.3 Cycling Test

The damper was connected to a 24VAC power source controlled by a cycle timer (see Figure 1). The relay changed the position of the damper about once per minute. A micro-switch attached to the damper and connected to a counter recorded each full damper cycle. Tolerances between the damper and the switch required that the damper close to within about 0.10" of its fully closed position in order for the cycle to be recorded. The damper was initially operated for a total of 4000 cycles, and continued testing was completed in an attempt to determine the number of cycles to failure.

2.4 Air Leakage Test

A Minneapolis Duct Blaster was used to induce air flow and measure pressures. The duct blaster was attached to the opening of the damper that is normally connected to the air handling system. The return air opening of the damper was sealed and the damper was positioned with the return air opening facing downward. A digital manometer was connected to the damper to measure pressures inside the damper relative to atmospheric pressure. With no power connected to the damper and the damper blade in the "recirculate" position, the duct blaster was operated to decrease the pressure inside the damper in increments of 5 Pa, up to –50 Pa. Duct blaster flow measurements were recorded at each pressure setting. The tests were repeated with the damper motor connected to 24 VAC (red-green leads) to determine whether continuous powering of the damper is needed to hold it tightly closed. Pressure vs. leakage rate graphs were developed using these data.

2.5 Pressure Drop Test

The damper was positioned as above, the seal was removed from the return air opening, and the duct blaster was attached to this opening. The damper was wired to 24V power to hold it in the "vent" position continuously during the test. The digital manometer was configured to measure positive pressures inside the damper relative to atmospheric pressure. The duct blaster fan speed was increased incrementally to achieve pressures, measured inside the duct blaster, of from 5 Pa to the pressure corresponding to the highest air flow the duct blaster could deliver. A graph of air flow vs. damper pressure was developed from these data.

3. RESULTS

3.1 Cycling Tests

After 4000 cycles the damper showed no signs of diminished performance. From the beginning of testing a small amount of play in the damper blade linkage to the motor was observed, but the damper seated firmly at both ends of its stroke.

Following completion of air flow and pressurization tests, cycling tests were resumed and are continuing. As of noon on April 5, the damper had completed 11,580 cycles without failure. At 10,000 cycles some hesitation was noted as the damper began to open and movement became jerky as the damper reached its closed position, probable signs of fatigue of the actuator.

If the damper were to operate daily April through October, it would cycle 214 times per year. Tests have therefore simulated over 54 years of operation. Based on these data, the damper motor, linkage, and bearings appear sufficiently robust for this application. Conditions of actual operation, including accumulation of dust and dirt in moving parts, could impose greater stress and result in a shorter life than demonstrated in laboratory testing.

3.2 Leakage Tests

Pressure inside the damper will be lower than atmospheric pressure during fan operation due to resistance to air flow through the return air grille. At a maximum expected air flow of 1200 cfm (during heating and cooling operation) the pressure drop through a typical 20 x 30 return grille is 0.035 inches w.c., or 8.8 Pa[1].

Figures 2 and 3 graph the results of the air leakage tests with the damper un-powered and powered, respectively. Damper leakage at a negative pressure of 8.8 Pa is about 47 cfm with the motor un-powered, and about 23 cfm with the damper powered.

Measured leakage with the damper powered, as it is in normal operation, is 1.4% of total air flow, given the pressure/flow characteristics of the 20 x 30 return grille. This meets the arbitrary maximum target established for leakage in the test plan of 2% of total air flow.

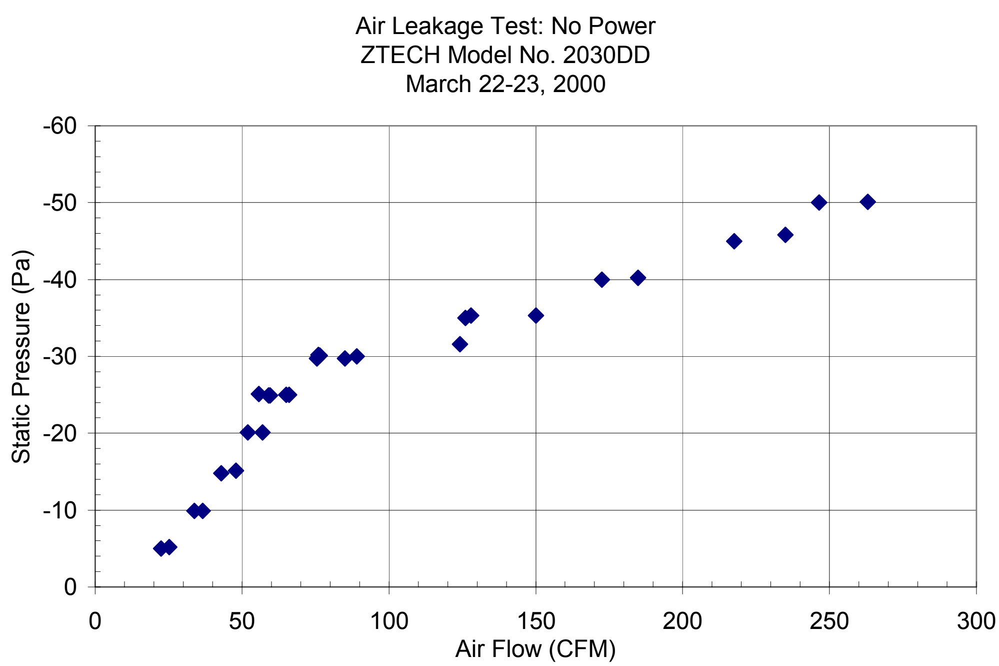


Figure 2: Damper Leakage – Not Powered

[1] Shoemaker 1075 Series, 20 x 30

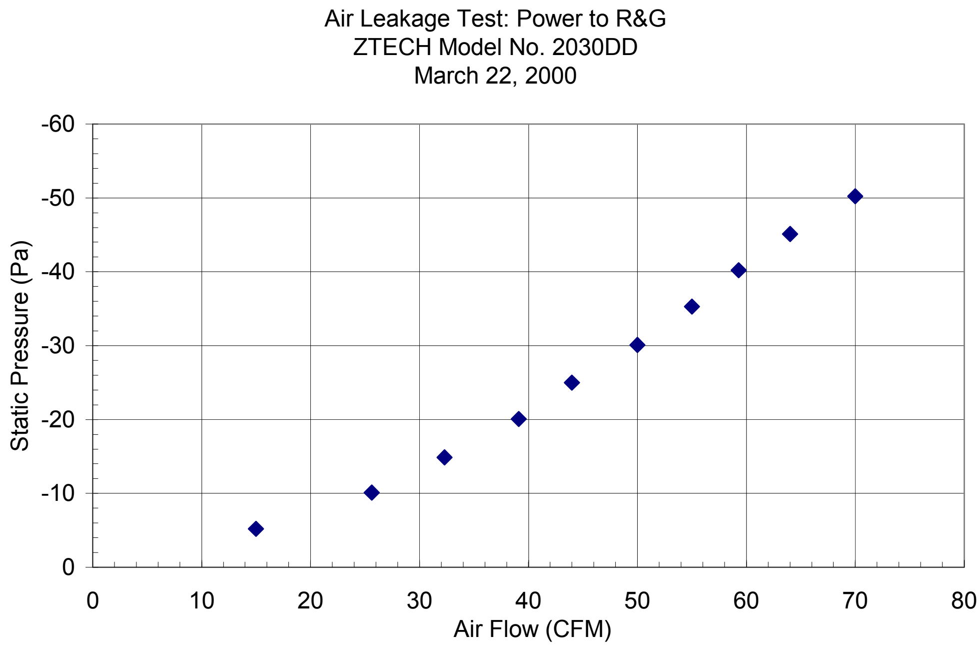


Figure 3: Damper Leakage - Powered

3.3 Pressure Drop Tests

Damper pressure drop test results, and a fit of the data are plotted in Figure 4. The equation of the curve fit is 0.00064 x $CFM^{1.79}$.

The effect of damper "back pressure" on house pressurization depends on house leakage. If windows are open, or if the house is exceedingly leaky, these alternate relief paths make damper relief pressure inconsequential. However, excessive pressure could be created in a tight house.

Test data obtained from a "Delta-Q" test performed by LBNL on a new house owned by a PG&E employee were used to develop a pressure-flow curve for the house. Using the pressure-flow equations for both the damper and the house, iterative calculations were completed to determine what pressure would be necessary to drive 2000 cfm through the damper relief and the leaks in the house. Results showed that the house would be pressurized to 25.6 Pa. Leaks in the house would absorb 1620 cfm and the damper relief would pass 380 cfm. This pressure translates to 0.10" w.c., or 0.02 psi. The force required to open a 3-0 x 6-8 door with this pressure applied would be 5.4 lbs. Since the "target" maximum value specified in the test plan was 5 lbs. (corresponding to 12 Pa), these results suggest that additional relief openings are not needed.

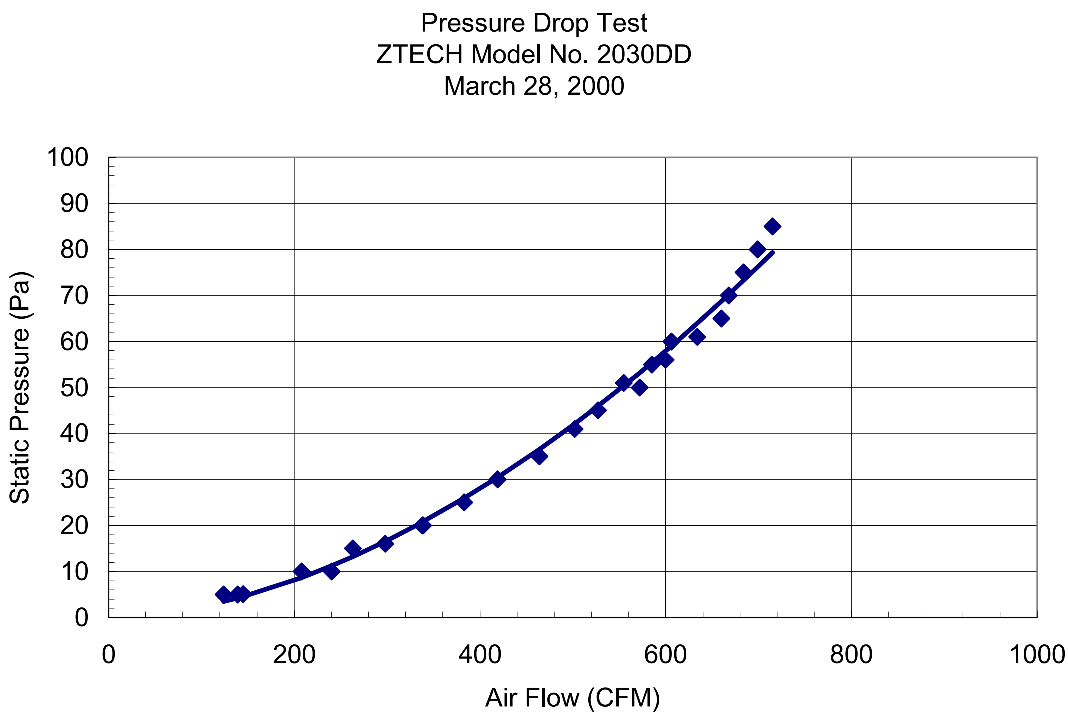


Figure 4: Pressure Drop Test Results

These results differ from measurements taken from SmartVent-equipped homes in Phase 3 of the Alternatives to Compressor Cooling project. Measured indoor pressures from these sites ranged from 4.2 to 13.0 Pa at air flows ranging from 1626 to 2589 cfm.

Motor performance curves and blower curves were also reviewed to determine the potential impact on power consumption of the high (25 Pa) static pressure. Blower motor energy should not increase by more than 50 Watts when pressure is increased from atmospheric to +0.10" w.c. (25 Pa).

4. CONCLUSIONS

Damper cycle tests suggest that the damper is not likely to fail over a 20 or 30 year system lifetime. The damper may outlast other components such as the blower motor, which has a projected lifetime of about 40,000 hours.

Damper leakage tests show that the damper seals are adequate, and perhaps far better than alternative damper designs. The measured 1.4% leakage will be accounted for in determining how to meet ventilation requirements for maintaining indoor air quality. Tests also showed that the damper should always be powered during fan operation to avoid excessive leakage.

Air flow tests conducted with the damper in the "ventilate" position suggest that the damper relief air flow path does not need to be supplemented with other relief dampers or operable windows to avoid excessive house pressurization. Further tests should be conducted with the damper installed in a tightly constructed house to verify these findings.